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PAPERS

ON SUBJECTS CONNECTED WITH

THE DUTIES

OF THE

CORPS OF ROYAL ENGINEERS,

CONTRIBUTED BY

OFFICERS OF THE ROYAL ENGINEERS.

NEW SERIES.

VOL. XI.

PRINTED BY W. P. JACKSON, WOOLWICH.

1862.

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PREFACE.

I must apologise to the Subscribers to the present Volume of the Professional Papers for its tardy appearance, caused in a great measure by my want of experience of the duties of Editor, and of the delays incidental to the Press.

The bulk of Papers III, V, VIII, X, XIII, and XIV, was originally read at the Friday Evening Meetings, at the Royal Engineer Establishment at Chatham, their writers having revised them for publication in their present form.

It will be observed with regret that with the exception of Paper X, there is no contribution from any of our brother officers employed in India.

C. S. HUTCHINSON,
Captain, Royal Engineers,
Editor.

September, 1862.

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PROFESSIONAL PAPERS.

PAPER I.

REPORTS ON THE TAKING OF THE FORTS ON THE PEIHO, AND THE ADVANCE ON PEKIN IN 1860.

TANG-KOO, 25th August, 1860.

SIR,

I have the honour to forward an account of the operations which resulted in the capture of one of the Peiho Forts and the surrender of the other four.

The weather having been tolerably dry for one or two days, and the intended tracks made practicable by fascines and drainage, the Force moved from Peh-tang at daybreak of the 12th, the left column (consisting of the 1st Division and the French), by the raised causeway; the right column (consisting of the 2nd Division and British Cavalry), over open ground inside the causeway which was very difficult at first but gradually improved.

The enemy's first position consisted of an intrenchment blocking the causeway, from which two ditches extended beyond the village, the inner one as far as the river; the Tartar Cavalry was drawn up behind the second of these ditches, where a mound of earth afforded them some slight cover. The right attack was commenced on this Cavalry by the rifled guns at about 1,000 yards; the Infantry drawn up in column in rear; our Cavalry in line upon the right. The practice was excellent and speedily drove the Tartars from their position, the greater portion of them filing off to their left; they were followed by our Cavalry who endeavoured to turn the ditches, and after some difficulty found passages over them, and the Tartars were soon driven off the field.

Meanwhile the intrenchment had been carried by the left column which joined the 1st on ground to the west of the Village of Sin-ho.

From the Village of Sin-ho one causeway leads onwards to the Fort of Tang-koo, a second at right angles to it, to the Pei-ho River. Soon after mid-day the French advanced their rifled guns upon the causeway towards the Fort and opened fire at about 1,500 yards from it, but without much effect, the swampy nature of the ground not permitting them to deploy to either side. It was observed that the ground upon the right near the river was higher and the Commander-in-Chief directed that it be reconnoitered and that the ditches between the cross road and the Fort be bridged over. Early the following morning I walked over this ground with Major Fisher to within 2,000 yards of the Fort, and found a broad belt of dry ground next the river which appeared to be still broader and harder nearer the Fort. Three wooden bridges, from 18 to 30 feet in length, were made by 10 A.M., of materials obtained by pulling down houses in the village, and the Commander-in-Chief reconnoitered the ground soon after in person to a point still nearer the Fort.

The same night a working party of 650 men, with a covering party of 500, proceeded from Sin-ho to a point 500 yards from the Fort on the river side, and excavated the musketry trench shown on Plan; the ground in front was at the same time examined to within 50 or 80 yards of the Fort on the extreme right; but a sentry being posted at this spot, and a continued shower of light balls proving that the defenders were on the alert, no closer examination was then attempted; the working party was withdrawn and the 1st Division with all the field guns and a French force advanced at daybreak of the 14th.

As Major Fisher conducted the Engineer operations on that morning I beg to enclose his account of them.

After taking possession of Tang-koo, the Engineers were employed in making two roads through the intrenched camp and town with the necessary bridges; also in collecting materials for a bridge across the Pei-ho. Major Fisher was intrusted with the construction of this bridge by the Commander-in-Chief's special appointment, and proceeded to the spot where it was to be formed on the 19th, with three officers and the 10th Company, Royal Engineers, to act in concert with a French working party and one sent from the British Navy.

The Bridge was finished on the morning of the 24th inst.

Sufficient stores having arrived on the 19th, and ten pieces of heavy ordnance having also reached the front, the 67th Regiment and Milward's Battery of Armstrong guns, with 36 men of the Royal Engineers and 117 men of Madras Sappers, moved on the afternoon of that day to within 2,000 yards of the upper North Fort, and constructed four causeways, in the position shown on Plan, to gain access to the Fort and to afford the means of reconnoitering the country on our left. A passage by the second causeway on the right having been made by dusk, the ground in front was reconnoitered to some distance by Major General Sir R. Napier, and at a later hour I again examined it more minutely, accompanied by Lieutenant Courtney, R.E., and an escort of 100 men of the 67th Regiment.

The result of this was that good hard ground was found to exist to within 200 yards of the Fort passable for guns, &c., without any obstacle.

Next morning the Commander-in-Chief and Staff, accompanied by the Major General, again reconnoitered the ground from both our right and left picquets proceeding along the causeways made the previous night. The result of the reconnaissance was that no advance seemed practicable from our left picquet from the numerous canals intersecting the ground in that direction.

All our efforts were therefore to be confined to our right attack, where it was determined to place five batteries. The position of these batteries having been determined by Sir R. Napier, I proceeded to trace four of them that afternoon with a party of 20 men of the Royal Engineers under Lieutenants Hime, R.E., and Trail, M.E., without much annoyance from the enemy, although a fire was kept up the greater part of the day, at intervals, by the forts, which was replied to by Milward's Battery of Armstrong guns. At dusk, Battery No. 2, for three 8-inch mortars, was traced by Major Graham, R.E.; this was 200 yards nearer the Fort than the other batteries, and was over a canal which was unbridged before that evening. The battery in this position was sheltered by the canal from the danger of a sortie.

At 7 P.M. the working parties paraded at the Royal Engineer Park as follows for the 1st Relief.

Infantry working parties 324 men, with 43 men of the Royal Engineers, to superintend, under the following officers:—Lieutenants Swanston, Dakeyne, and Foord, M.E. (Acting), and Harrison, R.E. The Madras Sappers, numbering 116 men, worked through both reliefs. Major Graham, R.E., was the Executive Engineer Officer for the 1st Relief, and Captain Shaw Stewart, M.E., for the 2nd.

The working parties were then marched down to their respective batteries, where they were employed till 11 P.M., when parties of similar strength relieved them. The subaltern officers of Engineers worked throughout both reliefs.

The following is a description of the batteries, &c. All were necessarily elevated not to lose the advantage of the hard dry surface for the platforms, and were intended to be 12 feet thick at top, and 3 feet 6 inches high en barbette, except the mortar battery, which was higher; advantage was taken of the mounds at the canal banks wherever they could be made to form part of the parapets.

Two of them were revetted with straw fascines which were obtained from an adjacent Tartar camp, in which they formed the sides and roof of the barrack rooms; these fascines averaged 12 feet in length by 6 inches diameter, and answered the purpose very well for the short period during which the bombardment continued. Two were revetted with sand bags from store. The mortar battery was without revetment.

Battery No. 1.—Battery No. 1 was 100 feet long, with two epaulments; it was intended for six guns to counterbatter the forts on the opposite side of the river, but was actually armed with seven, viz., one 8-inch gun and six French field-pieces.

This battery was under the superintendence of the Executive Officers and nine Sappers, Royal Engineers.

Battery No. 2.—Battery No. 2, for three 8-inch mortars, was 50 feet long and 6 feet high, erected under the superintendence of Lieutenant Dakeyne (attached to Madras Sappers). For this a small fuze fixing room was constructed in the adjacent canal *bund*. Two mortar platforms, which had been previously prepared in the Royal Engineer Park, were laid in this battery, the third platform being made of Chinese coffin lids, 6 inches thick, placed on the ground.

Battery No. 3.—Battery No. 3, for two 32-pdrs. and two 8-inch howitzers, was under the superintendence of Lieutenant Harrison, R.E. The parapet was 96 feet long; it had an epaulment 30 feet long and 6 feet high, in which a fuze fixing room was built of old materials from the village, 10 feet long, 8 feet wide, and 6 feet high. Platforms were laid of Chinese coffin lids placed on the ground.

Battery No. 4.—Battery No. 4 was for two 8-inch guns, under the superintendence of Lieutenant Swanstone (attached to Madras Sappers). The parapet was 50 feet long, it had a powder magazine on its right flank in a small epaulment. Platforms were laid of Chinese coffin lids placed on the ground.

Battery No. 5.—Battery No. 5 was for 6 Armstrong guns, under the superintendence of Lieutenant Foord (attached to Madras Sappers). Its length was 119 feet; on its left flank cover was thrown up for the limbers by making a half sunken battery 60 feet long and about 5 feet high.

DETAIL OF MEN, TOOLS, MATERIALS, &c., FOR BATTERIES.

NUMBER OF BATTERY.	MEN.			TOOLS.											MATERIALS.	
	Officers.	Non Com. Officers and Sappers.	Working Parties. Non Com. Officers and Privates of 44th and 67th Regiments, each Relief.	Picks.	Shovels.	Rammers.	Hand Saws.	Gimlets.	Hammers.	Baskets.	Lanterns.	Nails.	Adzes.	Sand Bags.	Fascines.
No. 1.	-	9	50	20	30	-	-	-	-	5	-	-	-	-	99
No. 2.	1	10	64	25	35	-	2	-	1	-	1	½ bag	1	-	-
No. 3.	1	10	78	20	50	4	2	2	1	20	1	½ ,,	-	480	-
No. 4.	1	10	52	20	30	3	2	1	-	-	1	½ ,,	1	280	-
No. 5.	1	4	80	30	50	2	-	-	-	-	-	-	-	-	52
	4	43	324	115	195	9	6	3	2	25	3	1½ bags	2	760	151

The Madras Sappers assisted at Batteries Nos. 1 and 2, and constructed in addition two causeways (across canals) leading to Batteries 2 and 4. The third causeway, in front of Battery No. 2, leading to the open ground in front of the Fort, was made at 4 A.M. by the working party from No. 3 Battery. Light balls were fired during the night by the enemy, followed by round shot, but no casualty occurred.

By 4 A.M., the guns, &c., were placed in the different batteries and everything got ready for the attack.

The Royal Engineers, 43 men in number, who had worked during the 1st Relief of the last night, were told off for the assaulting party in the following manner, viz.:—

Two non-commissioned officers and ten Sappers, under Lieut. Pritchard, R.E., with two Infantry pontoon bridges, one of 5 pontoons, the second of 8, to be carried by three Companies of Royal Marines, one of which was to be in reserve.

One non-commissioned officer, with six 24-feet ladders, under Lieutenant Hime, R.E., to be carried by a Company of Royal Marines.

Three non-commissioned officers and Sappers, with powder bags, &c., under Lieutenant Clements, R.E.

Eleven Sappers with carpenter's tools, and sixteen with miner's tools, under Lieutenant Trail, M.E. All these parties were placed under the charge of Major Graham, R.E. Lieutenant Courtney (Acting Adjutant), remained with me during the day as well as during the previous night, and rendered very valuable assistance in bringing up the assaulting parties, &c.

At 5 A.M. of the 21st, the enemy opened fire, which was soon returned and vigorously kept up from the guns on both sides. At 6 A.M. the magazine in the upper North Fort blew up, and half an hour later a magazine in the lower North Fort also caught fire from a shell thrown into it from one of the gun-boats. The enemy, however, was not at all disconcerted, but continued his fire without interruption; our field guns were gradually moved up to within 400 yards with the 44th and 67th Regiments in skirmishing order. At 8 A.M., before the fire was silenced, it was observed that the French were bringing up their ladders to that angle of the Fort on our right; the English assaulting parties were immediately ordered up and advanced towards the causeway opposite the middle of the work. The first pontoon bridge however was met by a tremendous shower of bullets and gingall balls, which battered in the head of one pontoon, killed one man, and wounded fourteen others; Lieutenant Colonel Travers, R.M., and Major Graham, R.E., being also wounded close by; also at the rear pontoon bridge, one officer and three men; and of the ladder party (there and subsequently), one officer and six men.

The causeway was now choked up, and it being found impossible to move the pontoons further, an order was given for the ladder party to move to the right, to second the movements of the French, the ladders were then used as bridges, and so great was the crowd of men over them that it was found impossible to remove them beyond the inner ditch; but as three French ladders were placed, some of our men got over the walls by them, and others by an embrasure, but not until after a long hand to hand contest. Meanwhile the powder bags had been carried round to the gate but could not be used against either it or the drawbridge, owing to the number of men crowding round them; measures were therefore taken to let down the drawbridge, which was fastened by a chain and several ropes; this was done in a few minutes by the assistance of Major Anson, Aide-de-Camp to the Commander-in-Chief, and several officers and men, and the passage was now open to some narrow openings which had been made in the walls at the same time on each side of the gate.

After this Fort had been taken a summons was sent to the lower North Fort to the effect that if it did not surrender by 1 P.M. it would also be assaulted; an answer in the negative was returned, and the allies advanced at 2 P.M., but on their approach the Fort was found to be abandoned, and the whole of the Pei-ho Forts were soon after given up on the sole condition that the inhabitants should be well treated; they were accordingly occupied.

During the night a passage was made by the gun-boats through the booms and stakes, and next morning they were able to ascend the Pei-ho.

As active operations in Northern China appear to have ceased at least for a time, I beg now to be permitted to mention the services of those officers and men of the Royal Engineers who have most distinguished themselves.

Major Fisher has so frequently been selected for special duties connected with this war, and performed them so satisfactorily, that his zeal and ability are already well known, but I should be sorry to miss this or any opportunity of adding my testimony as to the energy and skill with which his duties are performed, and the active assistance I have at all times received from him.

Major Graham conducted the assaulting party on the 21st inst., and when wounded with the bridge party and obliged to mount on horseback, directed the movements of the ladder party until his horse also being wounded, he was obliged to fall to the rear. Lieutenant Pritchard, and the other officers of the assaulting party were among the first to gain a footing in the Fort.

Of the Non-Commissioned Officers and Sappers, Sergeant Major Knight, Sergeant McEachran, Corporals Willcocks, Matheson, and Filkin, and Sapper John Squires, distinguished themselves.

From Captain Shaw Stewart, and the Officers and Men of the Madras Sappers, as well as those of the Royal Engineers, I have always received the most zealous assistance.

Of the Officers who have more particularly exerted themselves during the whole of the operations, I may be permitted to mention Lieut. Courtney, R.E., (Acting Adjutant), and Lieut. Harrison, R.E.

I have the honour to be,
Sir,
Your most obedient humble servant,
(Signed) G. F. MANN, Lieut. Colonel,
Commanding Royal Engineer.

The Deputy Adjutant General,
Royal Engineers,
Horse Guards.

Camp near Sin-ho, 25th August, 1860.

Sir,

I have the honour to report as follows with regard to the doings of the Royal and Madras Engineers on the 14th inst.

The Detachment paraded as detailed below* at about 5.30 A.M.

It was subdivided in the following manner:—

Royal Engineers.

1 Corporal and 20 men with intrenching tools, axes, &c.
1 Corporal and 30 men with pontoons.
1 Corporal and 16 men with scaling ladders.
1 Corporal and 10 men with powder bags.
The pontoons were carried by coolies.

---

* Royal Engineers—Major Graham, Lieutenant Pritchard, Lieutenant Harrison, Sergeant Hanson, and 80 Rank and File.

Madras Engineers—Captain Stewart and Lieutenant Filgate.

Madras Sappers and Miners—Lieutenant Swanston and 50 Rank and File.

The men furnished with intrenching tools being intended to carry the pontoons when under fire, their tools being left in a secure spot.

The Madras Sappers carried—

2 Scaling ladders.	1 Havildar and 16 men.
4 Powder bags.	1 Naigue and 8 men.
Intrenching tools.	1 Havildar and 23 men.

The Engineers formed the right of the line resting on the river, and advanced with the remainder of the Force until within about 1000 yards of the walls, when they were ordered to occupy some gardens and houses, and remain halted until required.

The action commenced at 8 A.M., and by 10 A.M. the enemy were driven from their guns by the fire of our Artillery as well as that of the Rifles who had advanced in skirmishing order, and occupied the trench made by the Engineers the night before.

At 10 A.M. the Infantry and pontoons were ordered to advance.

The Engineers formed a pontoon bridge of 5 cylinders which were carried to the front by coolies, as the enemy's fire had ceased.

The ladders, powder bags, &c., were also taken to the front. However, before the ditch was reached, a Company of the Rifles which was skirmishing on the extreme right found a means of crossing the ditch and entering the work at the point where it rested on the river.

They were followed by another Regiment. The Madras Engineers remained at this spot to improve the entrance.

The Royal Engineers moved to the left along the glacis and placed the bridge over the first ditch; a second bridge was made over the next ditch by means of one pontoon (which was not required for the first bridge) and some superstructure which was made at Peh-tang for the use of Infantry.

The bridge was composed of six baulks, 3 in. by 3 in., three of 15 ft., and three of 13 ft., which were let into the bank on either side and fastened to the saddle of the pontoon.

The chesses were of from $\frac{1}{2}$-in. to $\frac{3}{4}$-in. plank, 3 ft. wide, and cleated at either end so as to fit on the baulks without slipping.

Had there been another pontoon to spare it would have been well to have had it under the advanced end of the bridge, which might then have been launched right across the ditch.

The bridges being finished, steps were cut in the parapet to allow the Infantry to pass in, and the Engineers were then employed in clearing out the powder from the different huts near the walls and in general services in the town.

I have the honour to be,
Sir,
Your most obedient servant,

(Signed) A. A. C. FISHER,
Capt. Royal Engineers and Major.

The Commanding Royal Engineer,
Tang-koo.

TANG-KOO, August 26th, 1860.

SIR,

I have the honour to forward a description of a portable bridge which was prepared by Major Graham, R.E., from four scaling ladders and some boards, to enable the Commander-in-Chief to reconnoitre the inner North Fort on the Pei-ho on the morning of the 17th inst., as I believe it is the first time that the ladders have been employed in this manner.

It took precisely 15 minutes to put together from the time of the materials reaching the spot, it formed a very good bridge as well as for heavy horses as for Infantry.

I have, &c.,

(Signed) G. F. MANN,

Lieut. Col. Com. Royal Engineers.

The Deputy Adjutant General,
Royal Engineers.

REPORT OF A PORTABLE BRIDGE MADE OF SCALING LADDERS.

This bridge was required at almost immediate notice for a reconnaissance of the north Pei-ho Forts, to enable the General Commander-in-Chief and Cavalry escort to cross the canals that intersect the country about Tang-koo.

The width to span being about 23 feet, I had two lengths of scaling ladders firmly lashed, breaking joint by lashing a piece of wood about 3 feet long, by 4 in. by 2 in. on either side. Two lengths of ladder (24 feet) thus prepared were first passed over the ditch by means of a rope; this, two or three men crossed and placed on edge, so that the rounds lay vertical. The other double length of ladder similarly secured was then passed over, forming the other side of the bridge, planks 4 feet long, were then laid across, the outer edges being cleated below to prevent them from slipping laterally. To keep the ladders from falling over, earth was banked up and rammed at the sides of the ditch.

The bridge was laid and crossed by the General and Staff in a quarter of an hour, the only danger being from the rottenness of the planks, which consisted of old doors and shutters collected and prepared within an hour of the time required. With good 1½-inch planking, and a couple of side pieces to rack down, I believe the above to be a very good bridge for Cavalry or Infantry over ditches. On this occasion it was crossed by half a Company of Infantry marching *in step*, two deep, with files well locked up, without suffering the slightest injury. The weight of 24 feet of bridge is 750 lbs.

(Signed) C. GRAHAM, Capt. and Brevet Major.

Commanding 25th Company, Royal Engineers.

TIEN-TSIN, 9th September, 1860.

SIR,

I have the honour to report the Engineer duties performed since the 27th ult.

On the 28th, a party consisting of 10 Sappers, Royal Engineers, and 20 Madras Engineers, under the command of Captain Shaw Stewart, M.E., proceeded to Taku, where there were reported to be a number of fire junks. 80 old boats were found in a creek near the town laden with straw and wood in alternate layers, the wood steeped in sulphur, and saltpetre thrown over each layer in considerable quantities. The 80 boats were set on fire and destroyed.

The Pei-ho river being entirely in our possession, the stores left at Peh-tang have been removed to the Great Pei-ho Fort, and Peh-tang evacuated; one Sergeant and seven Sappers are left in charge of Royal Engineer stores at the Pei-ho Fort.

The 8th and 10th Companies left Sin-ho for Tien-Tsin with the 1st Division of the Army on the 30th, the 23rd Company followed with the 2nd Division on the 2nd September. The Madras Sappers were left behind to destroy the two small South Forts and erect jetties, &c., at the Great Fort.

Throughout the march, as well as in that made by the Cavalry on the north side of the river some days previously, not the slightest opposition was experienced, but the troops were everywhere received with the greatest apparent goodwill.

Several defensive works have been constructed in the neighbourhood of Tien-Tsin since 1858.

About 10 miles down the river are three enclosed batteries, one on the north and two on the south side of the river, to dispute the passage of gun-boats.

At a distance of 2,000 or 3,000 yards from the walls of Tien-Tsin, on both sides of the river, is a line of rampart and ditch intended apparently to prevent a bombardment of the city from the land; it is several miles in extent and consists of a simple line of thin rampart and ditch without flanks, and about the same section as that of Tan-koo. At the Southern extremity it abuts on two forts, erected one on each bank of the river; these forts are erected on the usual Chinese system with a cavalier in each and strong batteries bearing down the river.

The Commander-in-Chief being desirous of obtaining the best plan of the road to Pekin that circumstances will permit of, has appointed several staff officers to survey the line, and attached Lieutenant Harrison, R.E., to the Quarter-Master General's Department, temporarily, for the same purpose. Major Fisher would have been appointed to this duty, but he fell sick after the march up, and was yesterday moved to the hospital-ship at the mouth of the Pei-ho.

As there is some appearance of further active operations being necessary, one of the two Companies of Madras Sappers left to blow up the South Forts is ordered up the river.

Preparatory to the march towards Pekin, eight country carts have been added to the coolie transport, before provided for Engineer equipment.

The particular object of these carts is to carry a trestle bridge for the Cavalry and Artillery of each Division, as well as a light foot bridge. The trestles consist each of two tripods, which being fixed, the saddle piece is laid in a groove cut in each tripod to receive it; the superstructure consists of baulks and chesses, &c., similar to those of the pontoon bridge. Three carts carry one trestle and two bays, making 25 feet.

Half the 10th Company, under Lieutenant Pritchard, commenced the march for Pekin this morning, as part of a Detachment consisting of King's Dragoon Guards, one Regiment Sikh Cavalry, two Batteries Royal Artillery, half a Company Royal Engineers, three Companies Royal Marines, and 99th Regiment.

As the Head-Quarters moves on this afternoon, I close this letter now, it being probably my last opportunity of writing.

I enclose a plan of the ground in front of the upper North Fort, showing the canals and the position of the batteries, &c.

I have, &c.,
(Signed) G. F. MANN,
Lieut. Col. Com. Royal Engineer.

The Deputy Adjutant General,
Royal Engineers,
Horse Guards.

PEKIN, 25th October, 1860.

SIR,

I have the honour to forward a plan of the operations undertaken on the 11th and 12th inst., for the purpose of capturing the City of Pekin.

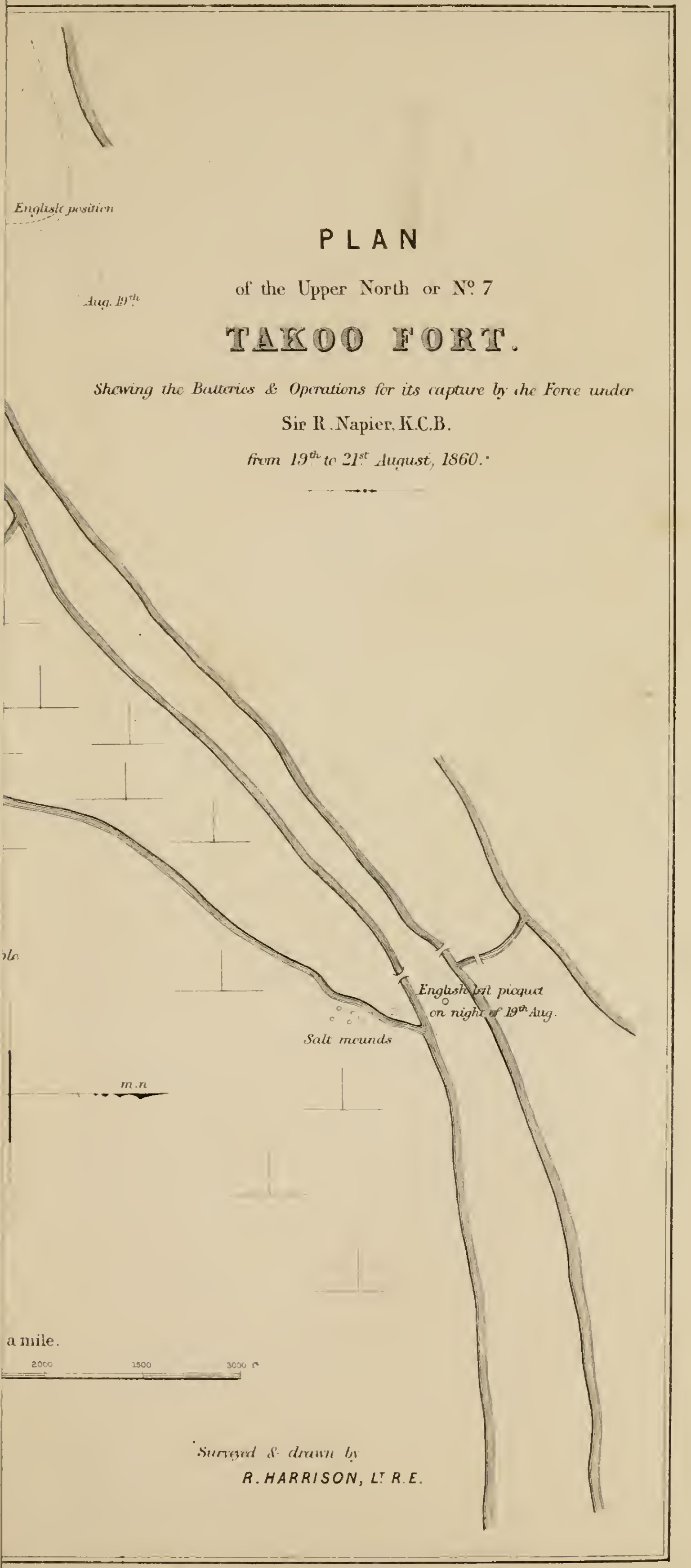
The walls and ground in front of them had been reconnoitered on the previous days, particularly between the North-East Angle and West Gate of north side.

It was there found that good cover by hamlets, hollow lanes, &c., existed to within 200 or 300 yards of the walls, and that heavy guns might be brought up to within that distance in several places without much difficulty or danger, whence the foot of the wall would be exposed to their fire. The walls themselves, however, are in good condition, of sound brick-work, averaging 40 feet wide, and without any houses close to their base, as is usual with Chinese cities; the ditch in front was found too inconsiderable to form an obstacle, and there are no outworks nor any means of effecting sorties except by the main entrances which are seen from a distance.

On the 10th, the Lieutenant General Commanding-in-Chief, accompanied by the French General and Staff, visited the enclosure called the Temple of the Earth (shown on Plan) and the grounds adjacent, and ordered that the necessary preparations should at once be made for attacking in that direction by means of a breach to be opened by four 8-inch guns behind the Temple enclosure wall, while the French prepared to form a second on our left by their 24-pdr. guns.

The same day the Royal Engineers and Madras Sappers took up their quarters at the Temple, with one Regiment of the Line, and the following works were commenced the next morning, all being under cover from the walls, viz.—

Embrasures for breaching battery and two openings for assaulting party in wall, which is 8 feet thick.



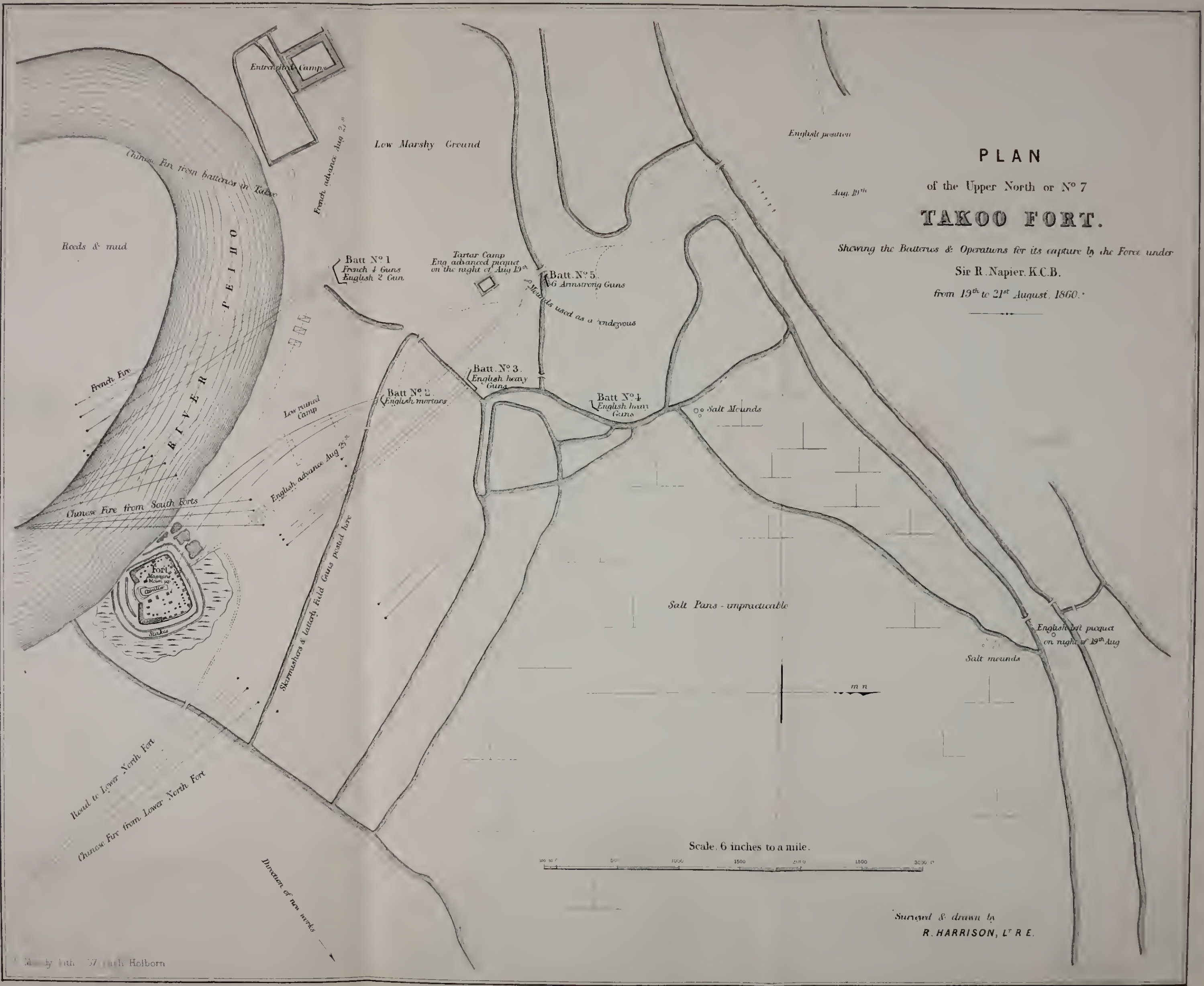
PLAN

of the Upper North or No. 7

TAKOO FORT.

Showing the Batteries & Operations for its capture by the Force under
Sir R. Napier, K.C.B.
from 19th to 21st August, 1860.

Surveyed & drawn by
R. HARRISON, Lt R.E.



PLAN

of the Upper North or No 7

TAKOO FORT.

Showing the Batteries & Operations for its capture by the Force under

Sir R. Napier. K.C.B.

from 19th to 21st August. 1860.

Surveyed & drawn by

R. HARRISON, Lt R.E.

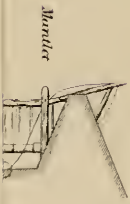
Mandy lith. 57 High Holborn

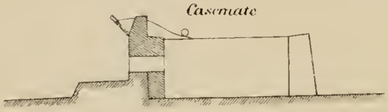
PLAN OF

UPPER NORTH TAKOO FORT, No. 7.

taken by the Force under Sir R. Napier, K.C.B.

Aug. 21st 1860.





Sections showing methods of sheltering the Guns.

Scale of Plan, 24" to a mile.

0 50 100 150 200 250 yds

Scale of Sections.

Horizontal distance 100'. & Vertical 50' to an inch.

Sketched & drawn by

R. HARRISON, Lt. R.E.

Moody Litho 257 High Holborn.

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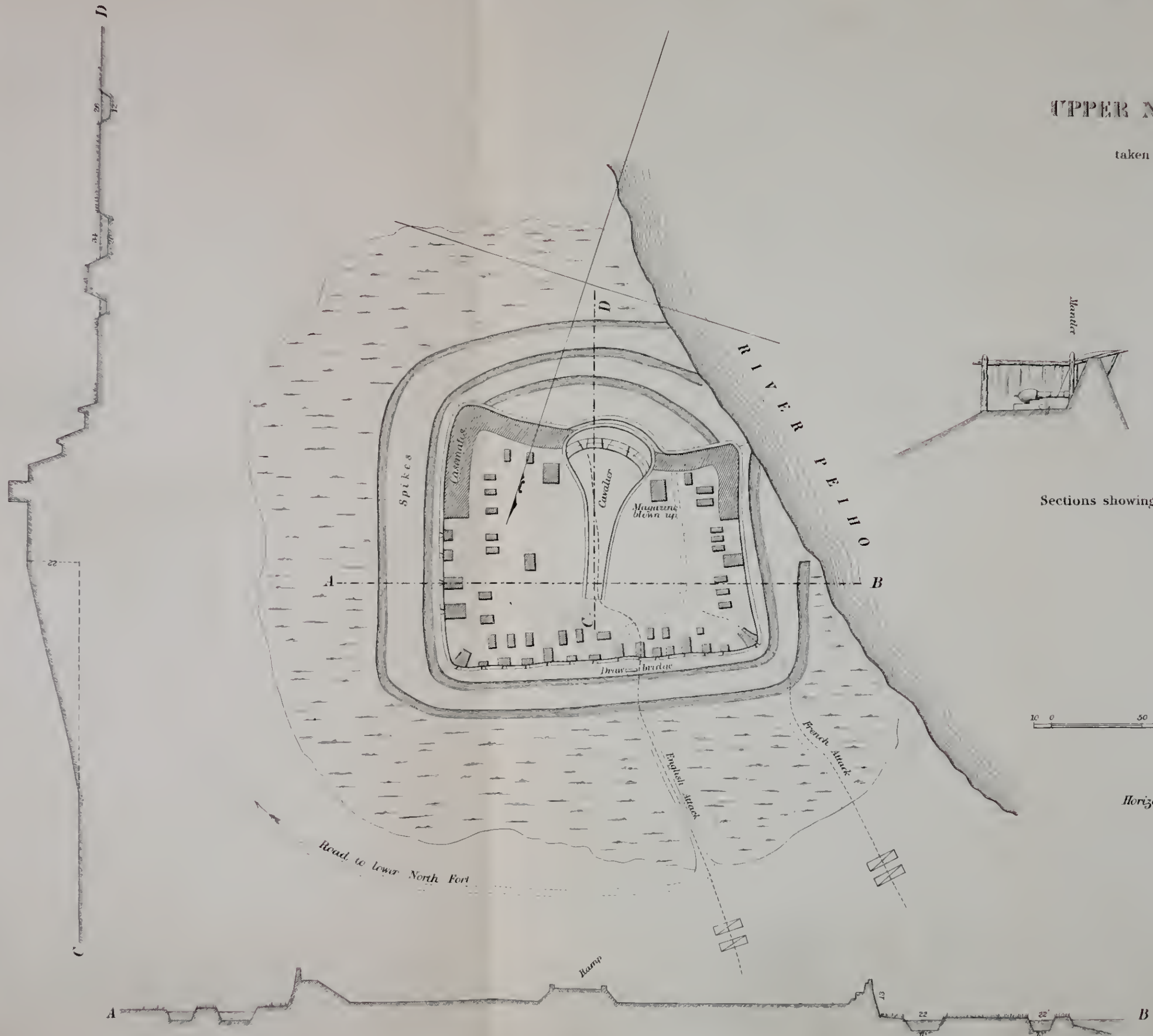

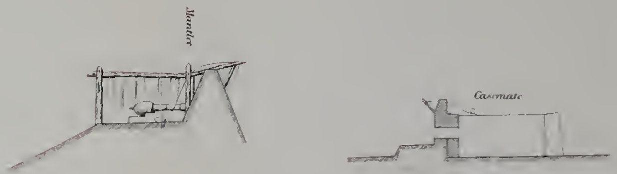

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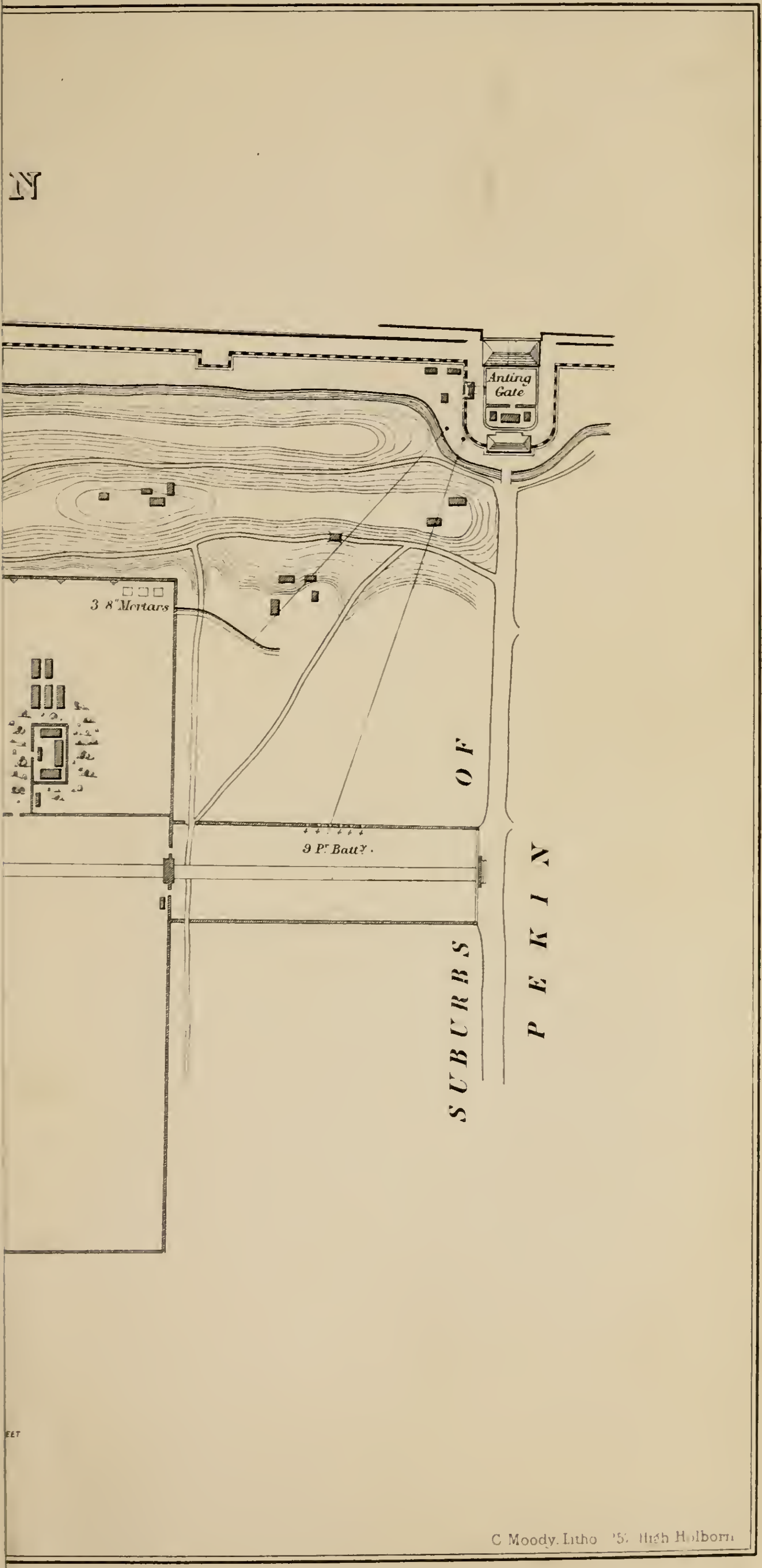

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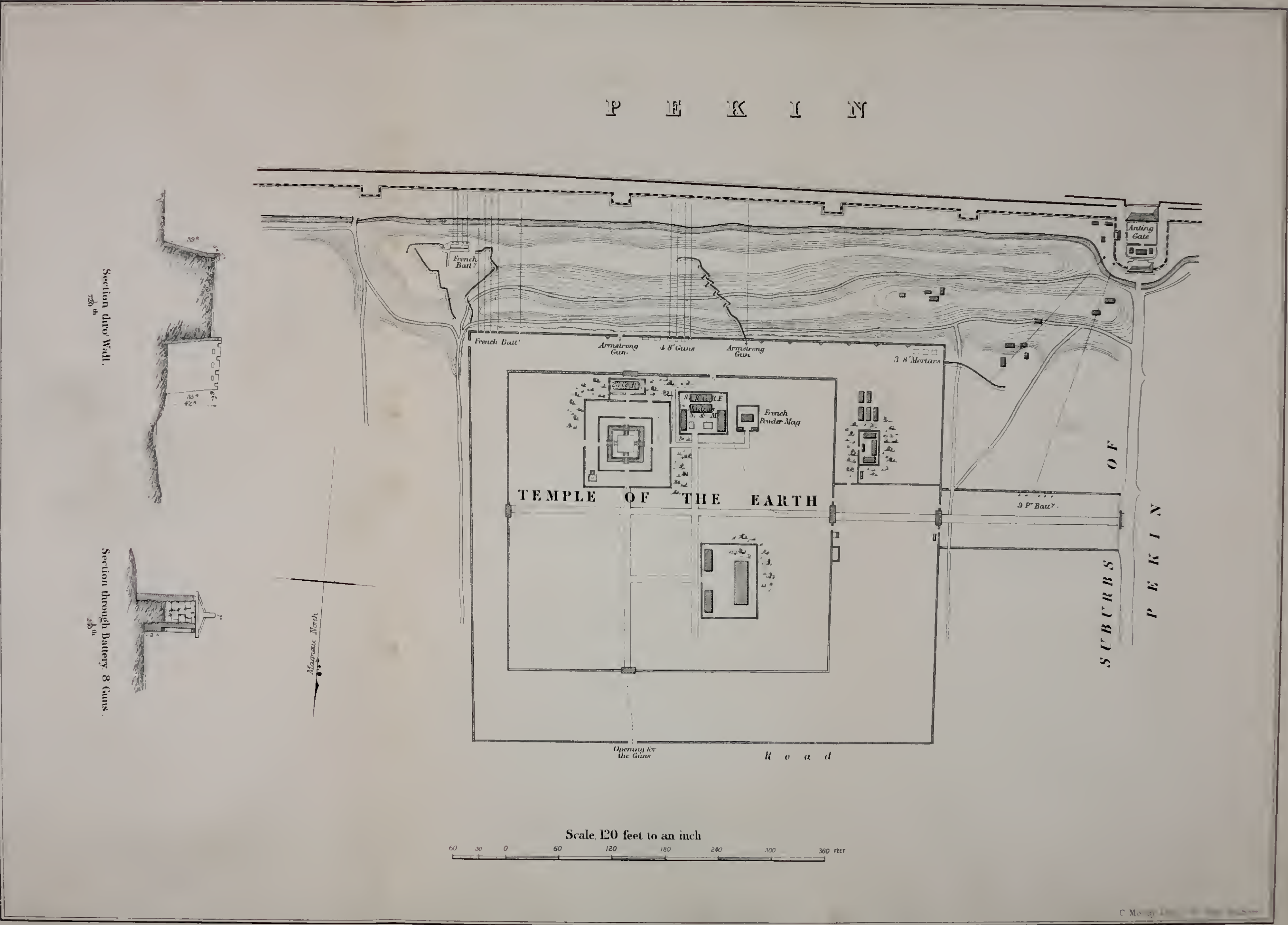

P E K I N
French Batt.y
French Batt.y
Armstrong Gun.
4 8" Guns
Armstrong Gun
3 8" Mortars
Anting Gate
French Powder Mag
S. K. C. R. E
S. & M.
TEMPLE OF THE EARTH
3 P.r Batt.y
SUBURBS OF PEKIN
Opening for the Guns
Road
Magnetic North
Section thro' Wall.
Section through Battery. 8 Guns.
Scale, 120 feet to an inch
60 30 0 60 120 180 240 300 360 FEET

C. Mo [illegible]

Formation of banquette behind the top of this wall by cutting away part of its thickness.

Opening walls in rear to afford an access for the guns almost entirely under cover.

The same works were proceeded with the following morning, and a site was levelled inside the enclosure for three 8-inch mortars; towards dusk the trenches were traced for the approach of the assaulting party to within 100 yards of the proposed breach, and to give cover for Riflemen against the gate and the walls near breach.

These trenches were formed during the night, the embrasures and passages through wall were opened out externally, and a battery for six field guns opened in the wall near the road to keep down the fire from the rampart over and near gate. The two openings for the assault were likewise fitted for field guns by a 3 feet 6-inch parapet of logs of wood which could be removed in two or three minutes. The village near gateway was also loopholed, and communication established through it, but it was not yet occupied.

These arrangements were made without the slightest opposition on the part of the Chinese, though they must have perceived that some hostile preparations were going on.

The breaching battery was ordered to be in readiness to open fire at noon on the 13th, and the assault to take place as soon after 4 P.M. as practicable.

A storming party from the 2nd Division was to ascend the breach, turn to the right along the ramparts, seize the An-Ting Gate, and maintain themselves there.

1 Captain, 2 Subalterns, and 40 Sappers of Royal Engineers and Madras Sappers, were detailed to accompany this party with short ladders and with powder bags and tools to overcome any obstructions at the gate; while for the purpose of distracting the attention of the only Chinese who were well situated to flank the breach, an Engineer Officer and 10 Sappers were to advance from the village with 20-lb. bags of powder to blow in the outer of the two gates.

At a few minutes before 12 the flag of truce was sent in, and the An-Ting Gate surrendered to the Allies.

I have, &c.,
(Signed) G. F. MANN,
Lieut. Col. Com. Royal Engineer.

The Deputy Adjutant General,
Royal Engineers,
Horse Guards.

PAPER II.

MEMORANDUM OF THE BLOWING UP OF A VESSEL IN THE MERSEY, OPPOSITE LIVERPOOL, IN 1845.

BY COLONEL CRAWLEY, R.E.

1. The Brig "Blemdel," 160 tons burthen, loaded with slates, glass, coals, and various articles, came into collision with another vessel in the river Mersey, in November, 1844, and sank in 80 feet water. She was weighed and conveyed to Seacombe-berry, where she grounded: a very high and rapid tide carried the brig further up the river, and she sank in 11½ fathom water, where she became a serious obstruction to the anchorage, and from whence all attempts to remove her proved ineffectual.

2. The Conservators of the River called upon the Corporation of Liverpool to remove this obstruction; the Corporation made an agreement with the Steam Tug Company to undertake to do so, and this Company applied to me for assistance. With the able co-operation of the Steam Tug Company's Officers, I undertook to direct and superintend the operation of blowing up the vessel with gunpowder.

3. Having procured the assistance of an experienced diver (one who had been employed upon the wreck of the Royal George), I directed him to examine carefully the position of the wreck and describe it to me. From his description I found the position of the brig to be as shown in the accompanying Figures 1 and 2.

Fig. 1.

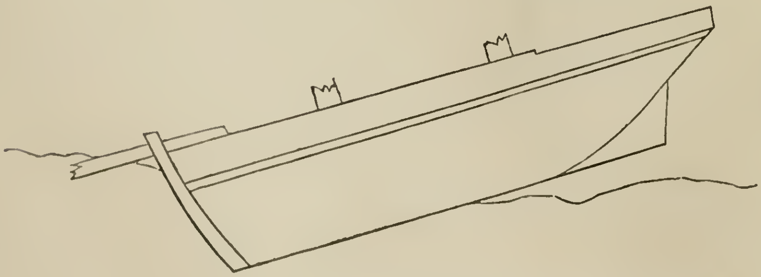
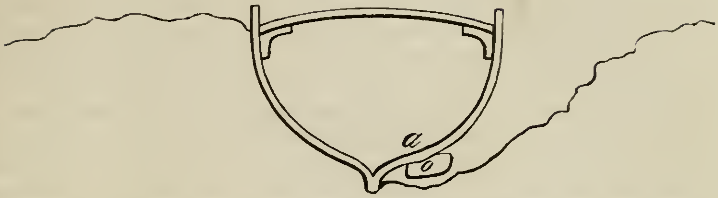


Fig. 2.

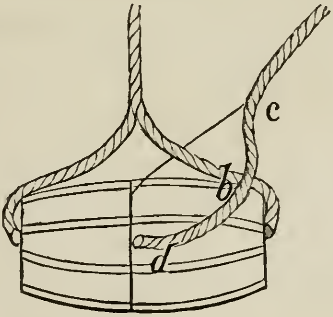


It will be remarked that the tide had washed away the sand from the starboard side, forming a gully to the level of the keel.

4. An eye-bolt was fixed at *a* by the diver, to which a block was attached, through this a line was reeved and fixed to the underside of the powder cylinder, thus forming a down haul. The cylinder was formed in the same manner as those used in demolishing the Royal George, paid over with similar waterproof composition, the conducting wire, of copper, $\frac{1}{6}$-inch, prepared, paid over, and bound with tape, precisely in the same manner as was done at the Royal George, and need not therefore be described at length here.

5. The first cylinder contained 300 lbs. of gunpowder, with a bursting charge of $\frac{1}{2}$ lb. of fine powder, placed in a piece of lead pipe, into which the conducting wires were led, the total length of these latter being 350 feet. The priming wires of platinum, No. 30, were used for igniting the charge, which was fired by a powerful Voltaic Battery consisting of 20 plates, 10 inches by 7 inches. In order to relieve the strain upon the priming wires, a line was made fast round the cylinder and lashed to the rope, on which the conducting wires were tacked, leaving the part next the cylinder slack as at *b*.

Fig. 3.



6. The first attempt was unsuccessful, for in lowering the cylinder the bight *(b)* caught in a projecting bolt in the wreck, and strained the priming wires so much that the water got in and prevented the explosion of the bursting charge.

7. To prevent a similar accident, the part of the conducting wire-rope from *c* to *d* was left only sufficiently slack to take off the strain.

8. On Saturday the 25th October, the tide being favourable, the cylinder containing 300 lbs. of gunpowder was lowered and placed at *a*, as shown in section (Fig. 2). As a further precaution against wet getting to the bursting charge, a tube of Indian rubber was placed over a wooden collar, the rope with the conducting wires was passed through this tube and lashed tightly to the conducting wire-rope, and the whole paid over with water-proof composition.

9. On completing the circuit, by applying the conducting wires to the poles of the Voltaic Battery, the explosion was instantaneous. The effect was to blow off the whole of the fore part of the ship, as far as the hold containing the cargo, the weight of which resisted any further extension of the effect. The bowsprit end, and large quantities of the debris of the wreck, came to the surface of the water. At the ensuing spring tides it was ascertained that the stern had parted from the vessel, and nothing remained but that part of the hull which contained the cargo.

10. Another cylinder was prepared to contain 400 lbs. of gunpowder, and the diver was directed to dislodge a certain part of the cargo to form a bed for this cylinder, 6 casks were removed and sent up by the diver; the cylinder was then lowered into the space prepared for it, and on the 7th November was exploded with complete success. The wreck was so far demolished that nothing remained but a few timbers standing up in the sand, which the next spring tide swept away, and the anchorage was entirely free from obstruction.

11. The difficulty attending this operation arose from the depth of water in which the brig lay (11½ fathoms), the almost entire darkness in which the diver had to work, owing to the muddy water of the Mersey, the rapidity of the tide, and the short time to work, not more than one hour during slack water neap tides. Remark may be made on the quantity of gunpowder used in each cylinder, but I considered it better to do the work as expeditiously and effectually as possible, and with few charges. Any smaller charges would have made the object to be obtained less evident, and might even have been considered partial failures.

H. O. CRAWLEY, Colonel,
Royal Engineers.

EXETER, 17th February, 1862.

PAPER III.

OBSERVATIONS ON LIMES AND CEMENTS; THEIR PROPERTIES AND EMPLOYMENT.

By CAPTAIN SCOTT, Royal Engineers.

It is surprising that little or no attempt should be made to improve the masonry of our fortifications, at a time when so much thought is given to providing efficient metallic protection against the destructive effects of rifled artillery. We cannot hope to plate with iron more than the embrasures and the most exposed portions of our defences; and the bulk of our revetments, magazines, and caponiers must still be of ordinary materials,—stone and brick, cement and lime mortars. Any suggestions, therefore, promising improvement in these materials, or in the mode of putting them together, are worth the consideration of the Military Engineer; and in this paper an endeavour will be made to point out the limes and cements best fitted for mortar; some of the fallacies commonly entertained respecting them; and the advantages which would result from removing their manipulation from the influence of the prejudices and of the convenience of workmen. The observations which follow were originally drawn up in the form of separate papers, and were read at the Friday Evening Meetings of Engineer Officers at the Chatham Establishment for field instruction. They are repeated almost as first written, such alterations only being made as were necessary to make them read continuously, to remove inaccuracies, or to render passages clearer.

On all points of importance on which conflicting opinions have been expressed by writers of eminence, their views have, excepting in a few instances, been given in their own language. This may appear tedious to some, but the writer believes that it will be more satisfactory to careful readers to have laid before them the data on which he has formed his opinions on disputed points, and thus to be enabled to judge for themselves.

In dealing with the subject, an explanation is first given of the action of mortars; then the results of experiments are adduced in illustration and confirmation of the theories advanced and the statements made; and, finally, remedies are suggested for the faults of our present practice, and some hints offered for the assistance of those who have to superintend the construction of works and feel that they require further knowledge than that which has been gained by rule of thumb practice.

1.—On the Action of Lime and Cement Mortars.

It is frequently supposed that, except in wet or damp situations, pure (or "fat") lime mortars attain great strength, and that there is no advantage in employing hydraulic limes excepting where the presence of wet or moisture renders a water setting material necessary. It is still more frequently, indeed generally, believed that though the limes do not set at first as rapidly as the cements, yet, that ultimately, they attain an equal or greater degree of hardness, and that the cements offer so much uncertainty in their use, as to make it advisable to use them as little as possible. A consideration of the causes which influence the setting of mortars will show that these ideas are probably erroneous, and this will be made quite evident by the proofs which will be adduced in the second paper, from observations made on their induration in actual constructions and in experimental trials.

Pure limestone, or carbonate of lime, when heated to redness is reduced to the condition of lime by the expulsion of its carbonic acid gas. The lime, when moistened with water, slakes with great violence, evolving much heat and crumbling to a soft, white, very bulky powder, which contains about $\frac{1}{3}$ of its weight of water. By a fresh addition of water, the bulk of the powder is considerably reduced, and the paste thus formed, if allowed to dry, shrinks and forms a porous mass of no great hardness. If the hydrate of lime were placed in a hermetically sealed vessel, either in the pasty or in the dry state, it would never, as far as we know, change its condition; the paste would remain a paste, and the dry hydrate always remain porous and friable. The hydrate of lime does not contain within itself any property by which a further solidification can be produced. When exposed to the air, however, both the dry and the pasty mass (which in the air soon becomes dry by evaporation) will gradually harden from the surface inwards, but always at a slower and slower rate, until, after the lapse of some years, no further perceptible progress is made. The hardening is due to the small proportion of carbonic acid gas which the atmosphere contains, and which restores the lime to its original condition of a carbonate. So far as this gas can penetrate, the pure limes, if used without foreign admixture, will harden and no further. In Plate 2, "Smith's Translation of Vicat," will be seen a sectional representation of the depth to which the carbonic acid gas had penetrated in 12 months into prisms of mortar, and these will enable an idea to be formed of the small portion of such mortar which can indurate in heavy masonry. In no part of the prisms does it exceed 2-5ths of an inch in depth, and the average is not more than 1-7th of an inch.

Alberti states that he had seen lime in an old ditch that had been abandoned about 500 years "which was still so moist, well tempered, and ripe, that not honey or the marrow of animals could be more so."*

It is stated by Jahn that in removing the ruins of the Castle of Landsberg, in order to lay the foundations for a new building, a lime pit of considerable dimensions was found in one of the vaults. The surface of this mass of lime was carbonated to the depth of a few inches, but all below that was in the state of freshly slaked lime, only somewhat more dry. This lime, which was certainly more than 300 years old, and valued at several hundred florins, was consequently used in constructing the new building.†

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* "Treussart, Mémoire sur les mortiers, &c." Sect. 1. Chap. 1.

† "Knapp's Technology." English Edition, p. 392. Vol. 2.

We cannot admit then," says Treussart, "that carbonic acid penetrates far into the interior of masonry, and it is proved by multiplied observations that moisture remains during a very long time in the interior of certain walls. Dr. Jahn reports on this subject that about ten years ago they demolished the piers of the Tower of St. Peters, at Berlin; this tower had been built 80 years, and the pillars were 27 feet thick, the mortar on the outside was hard and dry, but that in the middle was as fresh as if it had been lately placed there. I can state that in 1822, the lower part of a bastion, at Strasburg, being under repair, the mortar was found to be as fresh as if just laid, and nevertheless, this bastion was erected in 1666; the revetments was only about seven feet thick, but the moisture of the earth resting against it prevented the lower part from drying. Similar facts are observed in constructions still more ancient." *

"If then," says Vicat, "in what follows, we treat of ordinary mortars, or the mixtures of sand and rich limes, it is because we are compelled to do so to complete the history of the phenomena we have to describe. For it is our most decided opinion that their use ought for ever to be prohibited, at least in works of any importance." †

Sir Charles Pasley's testimony is characteristic, and the more valuable because he once held a different opinion—"I had ascertained," he writes, "more than 12 years ago, that the pure limes, such as chalk lime, Carrara marble, &c., were utterly unfit for the purposes of hydraulic architecture, as they dissolved away on the outside, and never set at all in the inside of walls exposed to the action of water. But I was of opinion at that time that the mortar of these limes was good for dry situations and for inside work, provided that the external joints were protected against the effects of beating rains, by pointing them either with cement or some superior sort of lime, which opinion I expressed in Article 10, near the commencement of the foregoing treatise. Having, however, acquired much more experience, partly from experiments, and partly in consequence of continual observations of new buildings in progress, or of old buildings being pulled down, since the first sheets of this work were sent to press, I am compelled to retract the above opinion in favour of chalk limes, which I now consider bad under all circumstances, even in the driest situations, as it never attains any great degree of adhesiveness, even when only exposed to the atmosphere, and its resistance is so insignificant, that it rather dries than sets in air. All that can be said in favour of chalk lime mortar is, that it is better than none; and that walls built with it will not fall to pieces in process of time, as General Treussart asserted, without external violence" . . . . and so, he continues, summing up his ideas on the subject in this pithy remark, which is almost the last of his valuable treatise. "Thus chalk lime mortar, when wet, is a pulp or paste, and when dry, it is little better than dust." ‡

"We are in the habit of composing our mortars," says Treussart, "of fat lime and sand, our mortars consequently have little durability. We shall not obtain durable masonry in the air until we can make use therein of hydraulic mortars. In countries where good hydraulic lime is to be had, no other kind should be used for any purpose whatever." §

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* "Treussart, Mémoire sur les mortiers, &c." Sect. 2. Chap. 11.

† Vicat. Smith's Translation. Chap. 11. Par. 207.

‡ "Pasley on Cements." Appendix CL.

§ "Treussart, Mémoire sur les mortiers, &c." Sect. 2. Chap. 14.

It might have been supposed that testimony so strong and unanimous, and from such reliable authorities, would have quite settled the question as to the unfitness of pure limes for fortification works at least, but so firmly rooted in the minds of our engineers was the old notion that good mortar could be made from pure lime (a notion by no means confined to *Military* Engineers) that we have, notwithstanding, used the fattest of limes for all the masonry at Gibraltar not exposed to the action of the waters of the bay, and within the last few years the pure Plymouth lime has been used for works at Devonport.* At Gibraltar when it became necessary recently to make some alterations in work which was 5 years old, and a portion of it was fired at with a 68-pdr. gun—the mortar, as was to be expected, was found to be set on the exterior surface only, and to be quite in a friable pulpy state inside. "We however think," says Colonel Owen, "that the parapet would have presented more resistance had the mortar been of better quality; far from having attained any peculiar hardness, as was expected by Sir John Jones, it was very friable, and had the appearance of having been imperfectly mixed." †

It is to be remarked that General Treussart was unacquainted with the superior results to be obtained by cements, and believed the results he obtained with strong hydraulic limes to be the best possible. His own experience of cements was confined to a few trials of Boulogne pebbles, which in character resemble the Roman cement stones of Sheppy and Harwich, and should have given a mortar of equal or nearly equal strength, but having calcined them in a very imperfect manner, he endeavoured to slake them in the same way in which he slaked his limes; and Vicat also, as Sir Charles Pasley remarks, "treats of natural cements in a manner which sufficiently proves his total want of practical knowledge of those cements." ‡

It will appear hereafter that Sir Charles himself, though he advocates so strongly their use whenever strength is required, asserting that their employment "does away with the thrust of arches," had no conception of the resistance of which the cements now manufactured are capable.

We have now to explain in what consists the superiority of the hydraulic mortars recommended by General Treussart, and of the cement mortars which General Pasley advocates, over the pure lime mortars. These, it will be remembered, have in themselves no property which can produce "setting" in the absence of the carbonic acid of the atmosphere; and that, therefore, where protected from this action, as in the foundations of a building, or in the heart of any heavy masonry, no solidification can ensue. The hydraulic lime mortars, however, do contain within themselves, to a greater or less degree, the property of solidifying without the assistance of the atmosphere, and this may be accounted for in the following manner.

Many impure limestones contain a proportion of clay (silicate of iron and alumina) intimately mingled with the carbonate of lime. By burning, the carbonic acid gas is expelled from them as in the case of the pure lime-stones, the clay assisting in its expulsion through the affinity of its silicic acid for the lime, and also parting with its own combined water. A further action then takes place: the silicic acid of the clay and the lime, at the high temperature of the kiln, re-act on one another, and either form a silicate of lime, or approximate to its formation so far, that on the addition of water it is formed with more or less rapidity. As, however, this action is more perfect in the water cements, and there is much in common between them and the hydraulic limes, it will be better here to explain in what their difference consists, and then to speak of them together.

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* According to Captain J. H. Wilson, R.E., the pure Plymouth lime mortar recently found under the platforms of Lower Fort, Plymouth Citadel, laid perhaps 50 years since, was quite soft and wet. He saw a workman beat some of it up with a trowel, without more water than it contained, and it was scarcely stiffer than new made mortar.—H. S.

† Corps Papers, New Series. Vol. 9, p. 45.

‡ "Pasley on Cements. Appendix LXXX.

The difference between them cannot be precisely defined with reference to chemical composition, for there are some limestones which will yield cement or lime according to the temperature at which they are burned. It must rather be referred to the manner in which they behave when moistened with water. If a piece of cement be dipped in water for a few seconds until it ceases to hiss from the escape of air from its pores, it may become harder, or it may after a time partially break up, with or without sensible warmth. If a piece of fresh pure lime be similarly treated, in a few minutes, as has been stated, it begins to heat and swell, and the violence of the action is such, as to throw it abroad in a bulky impalpable powder. In the latter case one affinity only comes into play, that of the lime for the water; but with the cement, a second affinity is in operation. By the action of the heat in the process of burning, the affinity of the lime for the silicic acid of the clay is brought into play and modifies the violence of its affinity for water; and when the temperature is sufficiently high, the lime and the silicic acid enter into chemical combination, and the compounds so formed, on being moistened with water, pass into hydrates in a gradual and quiet manner without any of that tumultuous action which is so remarkable in the combination of pure lime with water. The hydrated silicates resulting are not afterwards appreciably affected by water, and so much of the lime as the silicic acid can take up passes from a soluble to an insoluble condition, thus affording a cementing material suitable for hydraulic purposes. When the heat of the kiln is too far urged, vitrification ensues from the complete formation of an anhydrous silicate, and a comparatively inert substance is produced which undergoes no change on being mixed with water, or will only unite with it after considerable periods of time.

The hydraulic limes are intermediate between the cements and the pure limes, and partake of the character and mode of action of each class of substances. The proportion of clay in them is generally smaller than in the cements, and the lime sufficiently predominates to produce by its violent affinity for water the degree of heat, expansion, and amount of vapour requisite to throw them into powder. When the quantity of clay, as compared with the lime, is small, the violence of the slaking is scarcely less than that of the pure limes, but in proportion as the clay is relatively larger in amount, the heat generated in combining with water is less, and the lime slakes to a powder more imperfectly and with less increase of volume; until at last, on reaching the boundary of the cements, the slaking must be urged on by confining the heat generated, and the lime be allowed to lie longer to ensure the completion of the action before it is mixed with sand and made into mortar. The volume of the paste produced from the slaked powder of argillaceous limes is also less, generally, in proportion to the amount of clay present, and a smaller quantity of water is necessary to slake and bring them to that state.

Some portions of hydraulic limes, in ordinary kiln burning, are of necessity brought, by the too great heat of parts of the charge, to that condition in which the silicates formed combine with water very slowly, and such portions remain as unslaked concretions in hand-made or badly mixed mortar. These, by passing into the state of hydrate after the mortar has been laid in work, expand and frequently do much mischief, throwing down arches and even lifting large masses of heavy masonry.

The slaked powders of such limes consist of hydrate of lime, and of silicate of iron and alumina which have been converted in the burning into that condition in which, through the silicic acid having undergone a great modification, they can unite with the lime to form new hydrated compounds similar to those which result from the action of cements; the only difference appearing to be that, whereas in the case of the cements the formation of the silicates takes place previously to the slaking of the lime, or simultaneously with it; in that of the hydraulic limes their formation is a subsequent process, and occurs after comparatively long periods which may be measured by weeks, months, and years, instead of minutes, hours, and days. The solidification is assisted by the presence of water, as this dissolves portion after portion of the lime, and thus brings it into more intimate contact with the silicic acid. It is often observed that the induration of the best hydraulic limes, when immersed in water, proceeds most quickly on the outside, and that when they are allowed to dry rapidly, they never harden properly.

It will be readily understood that, just as in the case of the hydraulic limes, some portions, by too great heat, may have been converted into that condition in which the lime loses its energy for water, and can only be made to slake abroad by urging on the process; so, in burning cements, some parts of the charge may have had too little heat to bring about the perfect and rapid formation of the silicates aimed at. Such portions, though insufficient to generate by the slaking of the lime sufficient heat to cause the whole to break abroad on being moistened, yet retard the solidification of the mortar, and render the presence of moisture, if not of water, necessary to their attaining the ultimate degree of hardness of which they are capable.

The absolute proportion of the clay to the lime, and the temperature of burning, are not the only conditions which influence the action of cements and limes. It depends also greatly on the composition of the clay. A large proportion of iron and alumina (especially of iron), as compared with the silicic acid, greatly facilitates the action which takes place in calcination, and the prepared mortar also sets much more quickly. Thus the Roman, Medina, and Atkinson's cement stones, in which the quantity of the iron and alumina together nearly equals the silicic acid, are burned with little fuel at a low temperature, and the prepared cement, if fresh, sets in a few minutes. The Portland cement, on the other hand, in which the iron and alumina is less than one-half of the silicic acid, is burned at a very high temperature, and the cement should take as many hours to set as the Roman takes minutes. The same relation holds good between the composition of the clay, temperature of calcination, and rapidity of set in the case of the hydraulic limes. The larger the amount of the iron and alumina present, the more readily will the lime and the clay, when the limestone is raised to a red heat, pass successively from that condition in which the lime retains all its own proper energy for water, to that in which the lime and clay prefer, in partnership as it were, to enter into combination with it in a gradual and quiet manner, and to that in which the formation of the silicates is completed without the intervention of water, and the resulting vitrified compounds show themselves quite indifferent to it, or are only affected by it after having been submitted to its action for some time. When the first stage of calcination only is reached, and the lime slakes readily, the iron and alumina still assist greatly in expediting the subsequent formation of the silicates, and consequently there would be found wide differences in the rapidity of set between specimens of lias lime, grey chalk lime, and Dublin limestone, though they might each contain the same absolute amount of clay, because the composition of the clay in the three cases varies so much. The lias containing the largest amount of iron and alumina would yield the best result, and the Dublin limestone, in which the amount of these ingredients is particularly small, the worst. Many of the Dublin beds contain 20 per cent of clay, and yet yield poor hydraulic limes. Much of the Sheppy cement stone contains no more.

When the second stage of calcination is reached, such limestones as stand on the confines between limes and cements will yield cements, though at the lower degree of heat they produce only limes. The writer of this paper has prepared from one bed of chalk marl, simply by varying the temperature of burning, a hydraulic lime—a quick setting cement—and a cement resembling the Portland cement in character. In the last case the third stage of calcination was approached, when the iron, which had with the first and second degree of calcination remained in the condition of a peroxide, passed into that of a protoxide (as it always does in perfectly prepared Portland cement), one of the three equivalents of oxygen passing away in combination with the carbon of the fuel from every two equivalents of iron, owing to the high temperature and deficiency of atmospheric air. Had the clay been less in quantity, a hydraulic lime, with sluggish concretions, would have resulted when the substance was made into mortar, and the dangerous effects of after slaking, already alluded to, might have been apprehended. Had the proportion of the bases of the clay to the silicic acid been much greater, vitrification would have ensued before the last stage of calcination had been reached. It will be seen, therefore, that the property possessed by metallic oxides of enabling limes and the quick setting cements to indurate more rapidly, may interfere with that degree of calcination being reached, which in the Portland cement gives such wonderful results. Potash and soda are in this respect more energetic than iron; alumina alone, without other bases, does not vitrify with silicic acid excepting at the very highest temperatures.

As the cements may, and practically always do, partake of the slow solidifying action of the hydraulic limes, so the hydraulic limes partake, when exposed to the air, of the hardening action of the carbonic acid gas of the atmosphere to which the pure limes owe their external hard crust. From this action indeed the cements are not free, but neither in their case, nor in that of the best hydraulic limes, is this action of notable advantage. We may, however, have limes containing so little clay as to yield mortars hardly stronger than the pure limes, for the silicic acid can only combine with, and render insoluble, a certain proportion of lime, and whatever setting takes place beyond this must be due to the same ineffectual cause as that to which the pure limes owe their hardening. Much of the lime that goes into the London market under the name of Dorking, Halling, and Merstham limes, is of this character, and though tinged with iron sufficiently to give it the buff tint which has procured for the better sorts the appellation of "grey lime," yields no stronger mortar, practically, than what might be obtained from the whitest chalk pit.

The pure and feebly hydraulic limes (and indeed good hydraulic limes) are sometimes improved, as is well known, by the addition of puzzuolana, trass, &c. The action of such substances is similar to that of the clay found naturally mingled with the carbonate of lime in hydraulic limestones. They have been calcined by volcanic heat, and by this means the silicic acid has been brought into that condition in which it will enter into combination with the lime. Burnt clay will produce an effect similar in kind but rarely so perfect, and both with it and puzzuolana or trass, finer grinding and more intimate mixing, than can be accomplished with ordinary means in actual practice, are necessary to attain such results as have been arrived at experimentally in small samples. The fitness of such substances for preparing hydraulic mortars may be judged of by the quantity of silica which has become soluble in potash, after they have been acted upon by hydrochloric acid; for clay, which has been calcined in contact with lime or other metallic oxides, is readily attacked by this acid, and the silica set free assumes the gelatinous condition in which the alkalies can combine with it readily.

The pure and feebly hydraulic limes have, in massive brickwork, a very serious defect beyond that of want of strength, which defect is dependent on their inability to solidify out of reach of the air, and on the great hardness they attain where this comes in contact with them. The exterior joints of heavy masonry thus hardening with time, cease to be compressed by the superincumbent weight; but in the heart of the wall the settlement continues, and there a heavy pressure is thrown on the headers of the face bricks, which are thereby broken across, and the entire face of the wall becomes detached. In a perpendicular wall the face falls off, as lately happened at Fort Clarence, on the Medway. If the revetment slopes, the face may remain in position; but, manifestly, the wall must be seriously injured. An example of such injury occurred at Dover in the flank recently fired at with Armstrong and other guns in the presence of the Defence Commission. The face, though apparently sound, was detached by the space of a $\frac{1}{4}$ inch in many places from the back of the wall, and every header was broken across. The Armstrong shot cut through this detached face without much injury to the adjacent parts, but the round shot brought down large quantities at each discharge. The mortar inside this detached facing was so soft that it might have been re-worked almost without the addition of water. This revetment was stated by the Clerk of the Works, who had examined many of the revetments at Dover, to be a fair sample of them, and it must have been built for upwards of half a century. Another defect attending the use of such weak mortars in revetment walls arises from the mortars in the joint retaining sufficient water, or imbibing it again from time to time, to throw off the outer crust when it freezes. When this has happened a good hold is ready for vegetation which rapidly makes the mischief worse. Pointing is then resorted to, and this, as often as not, fails in the first winter from the freezing of the pulpy mortar behind, and in a few years the outlay in repointing amounts to a sum which would have covered the extra expense of building, in a good hydraulic mortar or cement, in the first instance. "There is no economy," says

General Treussart, "in putting up cheap masonry, which will require to be rebuilt at the end of a few years, and will need constant repairs annually; it is much better, and really more economical, to encounter at once the expense which will secure to the work an indefinite extension and exemption from all but trivial repairs."* It would be a curious point to ascertain how much has been spent on Tilbury Fort in the items of pointing and rebuilding since it was first erected. In some places the joints, from constant rescraping and the lifting effects of frost, which permitted the entry of dust after each repointing, have grown two inches, at least, in thickness.

It is necessary here to notice a very common error concerning the effect of sand on mortars. Doubtless there are cases in which sand of a peculiar kind, within certain limits, improves mortars; but, as a general rule, the action of sand must be injurious to their strength, and the only valid reason that can be given for its employment is the advantage gained in the first cost of a structure by the saving effected in material. In estimating the probable effect of sand upon mortar four points present themselves for consideration: the cohesion of the particles of the cementing material; their adhesion to the surfaces of the sand; the increase of strength that may arise, when the sand is stronger than the cementing material from the fracture having to take a longer path than it would, where no sand intervenes to break the direct passage in one plane; and the possibility of weak points occurring from several particles of sand remaining in contact without a sufficiency of cementing material to envelope them, and completely fill up their interstices. The latter consideration affects all descriptions of sand—whether granitic, calcareous, or argillaceous—pretty equally, and so far as this cause of weakness exists, the strength of mortar must suffer deterioration. So far as the particles of sand break joint, as it were, and thus lengthen the path of the fracture, something doubtless is gained by its use, especially when the sand is intermixed with gravel, and its grains are of various sizes. In respect to the question of adhesion as compared with cohesion, wide differences may be supposed to exist, according to the nature of the surface of the sand, whether rough or smooth, and according as the lime is capable or not of exerting a chemical action upon it. Now, as far as is known, the lime of mortar has no practically appreciable action upon quartz sand; and, therefore, as the greater part of our sand in this country is granitic, the adhesion of the lime to it must be independent of chemical effect, meaning by this term the formation of any new compound. In France, however, a sand is found, termed an arène, which is a description of puzzuolana, and the employment of this sand has a decidedly beneficial action upon lime mortar. A ferruginous sand, found in the gravel pit close to Prince Frederic's Bastion, on the Chatham Lines, possesses similar qualities, and it is probable that brick dust and burnt clay, as in some instances they form fair substitutes for puzzuolana, would also, in a coarse state resembling sand, have also a beneficial effect both on pure and hydraulic limes, though not, perhaps, on cements, because these naturally contain all, or nearly all, the clay which the lime can chemically combine with. But with the majority of sands such chemical action is wanting, and the sand and lime particles hold together by the force of adhesion only. Experiments show that with most surfaces this force, as can readily be conceived, is less than that of the cohesion between the particles of lime. The addition of sand, therefore, generally introduces an element of weakness into mortars in this way also. The loss of strength in respect of this will be greater in proportion as the sand is finer, and as the quantity is increased, for by enlarging the extent of surface over which adhesion takes the place of cohesion, not only is something absolutely abstracted from the resistance of the aggregate mortars, by a lesser force being substituted for a greater, but the chance of weak points, from a deficiency of cementing material between the particles of sand, is increased. We introduce then into lime pastes three elements of future weakness when we add sand to them, arising from imperfection of mixture, and from the substitution of the weaker force of adhesion for that of the cohesion of their particles. We give them one element of strength by interposing, in the direct path which fractures might otherwise take, grains of a material stronger than themselves. It seems probable, however, that the advantage thus gained does not counterbalance the sources of weakness introduced, and it will be seen hereafter that experiment proves this to be the case. Experiment shows, too, that there is little difference of resistance between mortars made of fine, coarse, and mixed sands, though as the sand approaches the size of gravel the diminution of strength from its addition becomes notably less.

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* "Treussart, Mémoire sur les mortiers, &c." Sect. 2, Chap. 16.

It was Smeaton who first pointed out the error, then upwards of 2000 years old, that the superiority of lime consisted in the hardness and whiteness of the stone from which it was prepared. The fallacy about whiteness is exploded, but the idea of the connection between the goodness of mortar and the density of the limestones yielding it, is still entertained by many practical men; and when the Dorking and Halling grey limes were first brought into the London market, it was considered necessary to call them "stone limes" to procure their introduction. In many of the builders' price books they are still so termed.

Supposing the pastes of limes resulting from the burned limestones were proportionate to the density of the original stones, this notion, of the connection between the density of the limestone and the strength of the mortars they are capable of yielding, would probably be correct, but there is no such relation. Pure mountain limestones and chalk yield mortars of precisely similar quality though the stones are of very different densities; and the reason of this can readily be understood. The pure mountain limestone, though a cubic foot of it may weigh 173 lbs., produces a paste of lime no denser than that of chalk lime, which weighs only 140 lbs. the cubic foot: that is to say, all other things but the density of the limestones being similar—such as the purity of the limes, their freshness, the mode of slaking, and the proportion of water employed—the quantity of paste produced will be in proportion to the actual quantities of lime contained in a given bulk of the limestones, and the density of the pastes will be equal.* In argillaceous or hydraulic limestones, it is possible that density may assist in bringing about that reaction between the silicates and lime during their calcination, which enables them to unite in the manner already explained; and with cement limestones, which yield a substance capable of slaking and setting simultaneously without notable expansion, the original density of the stone undoubtedly does affect the density of the hardened mortar resulting from it; but with pure limestones, if the original density of the stone affect the result at all, it must act in a manner contrary to that which is usually supposed, and take from the compactness and hardness of the set of the mortars made from them; for, in consequence of the greater development of heat within a certain compass on slaking, the lime would be reduced to a finer and bulkier powder, yielding a more voluminous paste and a more porous mortar when the water dries out.

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* Colonel Harness stated in a discussion on this subject, that the results of experiments tried by himself at Bermuda appear to bear out the view here taken. He had found no difference in the quality of limes made from the very soft limestone of Bermuda and the indurated coral limestone of the same island; the latter also gave a greater bulk of paste of lime than the soft lime in the proportion of its greater specific gravity.—H. S.

It is necessary to observe, however, with reference to this question, that a process was recently discovered by the writer of this paper, by means of which *limes* can be made to slake and set simultaneously after the manner of cements; and when so treated, the dense limestones yield the most compact and hardest mortars; but this is a different case, and the opinion generally held that the dense limestones yield better limes than those which are porous, simply in virtue of their greater density, is quite untenable.

In the foregoing remarks the worthlessness of pure or fat lime mortars for all constructions, and especially for such as involve the use of heavy masonry, or which will remain damp for any length of time, has been insisted on; and it has been explained that their unfitness for thick and damp walls results from their not containing within themselves any property by which solidification can be brought about. It has been stated that the hydraulic limes and cements do, to a greater or less degree, contain within themselves the elements of solidification independent of the action of the atmosphere, by which alone the pure limes can harden; and an endeavour has been made to explain the conditions which are necessary to the production of good mortars. The commonly received principle of the advantage gained by adding so much sand as will just leave interstices sufficient for the lime paste to fill up, has been opposed; and this principle, if it were a sound one, should apply equally to all limes not in themselves of a sandy nature, and this is not pretended. The correctness of the idea that there is a necessary connection between the density of limestones and the goodness of the mortars prepared from them has been impugned; and it may be remarked in conclusion, that the notion commonly entertained of the efficacy of grouting is much exaggerated. If the joints of work are not properly flushed up, undoubtedly grouting is of great advantage, especially when dry bricks are employed in work, but the strength of grout cannot at all compare with that of good stiff mortar; for grout, when the water dries out, is merely very porous mortar, and the more fluid the grout the weaker the work will be. We shall now attempt to show that all the assertions made, and theories advanced in the foregoing remarks concerning the setting properties of limes of different composition are fully borne out by the experiments of those who have made the strength and action of mortars a subject of special enquiry.

2.—Pure and Hydraulic Limes;

The Agreement between Theory and Experiment.

The authors who have studied most attentively the action of limes, and first attempted to express numerically their resistances as dependant on chemical composition, are Vicat, Colonel Raucourt de Charleville, and General Treussart. The two first of these writers entertain very similar views on the subject generally, and Colonel Raucourt de Charleville acknowledges the assistance he has derived from Vicat, but, unfortunately, both of them have adopted methods of making and recording their experiments which are far from satisfactory. Colonel Raucourt de Charleville has deduced the resistances in the Table following, from the number of revolutions given to a gimlet loaded with a fixed weight to enable it to penetrate a certain depth into prisms of hardened mortar; and Vicat has apparently attempted to deduce the resistance to a force of traction from experiments on prisms exposed to transverse strain. Although, however, the numbers arrived at by Vicat, may convey little idea of the absolute resistances of the mortars specified to any kind of force, they are very valuable as showing the relative position of different limes as regards strength, and Colonel Raucourt de Charleville's Table pretends to no more than this.

TABLE I.

Showing Colonel Raucourt de Charleville's estimation of the resistance to rupture, of the mortars of limes of different quality and of various stones:—

Description of Lime or of Stone Experimented on.	Comparative Resistance.
Eminently hydraulic mortars of quartzose sand	11 to 6
Hydraulic mortars	6 to 4
Feebly hydraulic mortars	4 to 2
Bad ordinary mortar of common lime and quartzose sand, such as masons use	scarcely above 1
Soft gypsum and freestone	1 to 6
Lavas and tufas	6 to 10
Soft limestone	10 to 20
Brick of good quality	12
Hard limestone	20 to 40
Granite	40 to 50
Basalt	50 to 70
Quartz rock	70 to 80

TABLE II.

Showing Vicat's determination of the resistances of small prisms of lime and sand, and of certain stones:—

Description of Lime or Stone Experimented on.	Per centage of Clay in the Limestone.	Comparative Resistance per square inch. lbs.	REMARKS.
The eminently hydraulic limes : .	20 to 25	170·8	The proportion of sand in the mortars not stated.
Ordinary do. do. . .	15 to 18	142·34	
Hydraulic limes of medium quality	8 to 12	99·64	
Rich limes	0 to 6	42·7	
Bad mortars	do.	10·67	
Limit of greatest resistance of eminently hydraulic lime . .	20 to 25	263·7	
Basalt of Auvergne	...	1096	
Limestone	...	284·7	Not hard enough to bear polishing.
Soft stone used at Paris	...	142·34	

The next Table given is extracted from Sir C. Pasley's work on limes and cements.* In that work the results will be found in full in Tables VI. and VII., but here it is considered better to give the means only, as including the result of a larger number of comparisons at one view. Although the individual trials of the two limes varied in their conditions as to the proportion of sand and ballast, yet with each lime the circumstances were, in the main, about equal, and equally affected their strength.

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* Pasley, Limes and Cements, pp. 134, 135, and 136.

TABLE III.

Showing the result of comparative trials on prisms, 2 inches square in section, and 3 inches between the points of support, broken by a transverse strain on their centres:—

Description of Lime.	No. of Trials.	Days before Immersion.	Age, when broken, in days.	Parts of Sand and Gravel to 1 part of Lime.		Fracturing weight in lbs.	REMARKS.
				Coarse Sand (S), Fine (s).	Gravel.		
White Chalk	11	Not immersed.	385 to 463	2 s or 3 s or 2 S and 1 s or 3 S and 1 s or 1 S and 1½ s or 2 S and 1 s	3 to 10	53	Sometimes made with hot water, sometimes with cold, but this caused no difference in the results.
Halling	8	do.	412 to 463		3 to 11	78	
White Chalk	6	18 to 33	433 to 457		3 to 9	48	
Halling	16	18 to 36	433 to 457		3 to 11	115	
White Chalk	16	Not immersed.	240 to 271	3 to 11 parts of Ballast.		76	The amount of sand in the ballast not stated.
Halling	16	do.	240 to 270			102	

Observations on the foregoing Tables.

There is a fair amount of agreement between Tables I. and II., but as Table II. gives the per centage of clay belonging to each class of lime, there is more certainty in its use and it is alone referred to in the comparisons hereafter made.

Table III. shows that, under the conditions of the experiment, white chalk lime, in small masses of concrete, attains about $\frac{2}{3}$ of the strength of Halling grey lime when both are exposed to the air from 9 to 16 months. When the prisms of concrete were immersed after they had been formed for periods varying from 3 to 5 weeks, those of the white chalk lime lost but little of their strength notwithstanding the injurious effect which water is known to have upon such lime. This resistance to its influence must be ascribed to the action of the air upon it before immersion. The exterior film of lime becoming carbonated protected the interior portions to a great extent from the influence of the water; without such protection the prisms must have been entirely disintegrated, as lime is entirely soluble in water, when not chemically combined with silica; and if there were any action between the gravel and the lime, this could only have taken place where their surfaces were in contact, and could not have prevented the destruction of the prisms. A similar carbonated crust most probably assisted the Halling lime prisms also, for neither is this lime, unless made from the lower chalk beds at Burham, sufficiently hydraulic to resist the direct action of water, though it is quite evident that the moist condition was more favourable to its hardening than the dryness resulting from exposure to the air. This so far illustrates the observation made in the first paper that moisture was necessary to the perfect induration of the hydraulic limes.

Let us see, however, how far these results agree with Tables I. and II.

According to Vicat's classification, white chalk lime would have been placed with the fat limes, but as he includes in the class of fat limes all limes prepared from limestones containing 6 per cent of clay and under, it would not have been at the top of the class; neither would it, if properly mixed with the sand or gravel employed with it, fall so low as what he characterises as "bad" mortar. It seems fair, therefore, to put the prisms of General Pasley's experiments, which were very carefully made, somewhere near 40 lbs. per square inch on Vicat's scale.

The Halling grey lime contains, on an average, 8 per cent of clay, and the lime it yields would, therefore, be classed amongst the lowest of Vicat's limes of medium quality, and we may fairly assign to it a resistance of 80 lbs. On Vicat's classification, therefore, the relative strengths of the chalk and Halling limes should be as 1 to 2. Now, putting together the results of General Pasley's three sets of experiments, we find the aggregate resistance of the chalk limes to be 177; of the Halling lime 295 lbs.; or nearly as 1 to 1·7. Remembering that the Halling lime evidently suffered from too rapid desiccation, excepting in one of the three sets of experiments with it, no closer result could have been expected; on the contrary, our confidence in such experiments should be increased by so near an agreement.

Table II. affords an illustration of the observations made above on the impossibility of always deciding, from the quantity of clay which a limestone may contain, whether it will yield a cement or a lime. Vicat here classes as limes substances containing as much clay as Portland cement. The amount of argillaceous constituent added to the chalk in the manufacture of that cement is exactly that which Vicat assigns to his eminently hydraulic limes.

In Table IV. following, compiled from experiments by General Treussart,* the prisms were first made 6 inches long and 3 inches square in section. When they had been moulded for 12 hours, they were placed in water, and remained there for one year. At the end of this period they were subjected to trial after being reduced in size until they measured 2 inches square in section. General Treussart noticed that, in taking off the outside portion, the mortars were often found to be softer inside than on their outer crust, but that sometimes the contrary was the case. He does not state in what instances these differences occurred; but it is more than probable that those which hardened fastest on the outside were the richest in clay of a favourable composition. If this supposition be correct, the influence of the water on uncombined lime, and its action in facilitating the formation of the insoluble silicates produced in the setting of hydraulic lime, as explained in the first paper, would fully account for these differences.

The experimental prisms of "fat" lime and sand were not immersed in water, that being a test which General Treussart knew them to be unable to withstand, but were left to harden, for one year, in a cellar. The mixture of fat lime and trass was treated like the prisms of hydraulic limes.

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* "Treussart, Mémoire sur les mortiers, &c. Sect. I. Chap. 2 and 3.

TABLE IV.

Showing the volumes of dry powder produced by slaking 1 part of certain limes; the volumes of water necessary to slake and bring 1 part of them to stiff pastes; the volumes of these pastes; and the resistance, after 12 months, to transverse strain of prisms of mortar made with them, and of like prisms of brick:—

Name of Lime or other substance subjected to trial.	Volume of Powder produced by Slaking.	Volume of Water used to bring the Limes to Paste.	Volume of Paste produced.	Composition of Mortars of Prisms.							Remarks.
				0 Sand 1 Lime	1½ Sand 1 Lime	2 Sand 1 Lime	2½ Sand 1 Lime	2¾ Sand 1 Lime	3 Sand 1 Lime	1 Sand 1 Trass 1 Lime	
				lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
Fat Lime of Strasburg . . .	3½	2	1¾	...	...	68	44	10	0	499	The Lime measured in paste. Immersed only in the case of the Trass mixture.
Villé Lime (2 samples) . . .	3⅓	1½	1½	114	...	91	...	...	...	384	The Lime measured in slaked powder.
Metz Lime	2⅓	1⅙	$1\frac{1}{20}$	169	312	264	176	...	143	466	
Verdt Lime	2¼	1	1	484	...	279	...	...	...	510	
Grey Obernai Lime	2	¾	1	354*	400	422	187	...	106	473	
Altkirch Lime	1⅚	⅚	1	268	...	174	...	...	...	539	
Boulogne Cement	1⅙	½	¾	286	...	...	...	...	...	...	
Common Brick of Strasburg .	...	...	...	462	...	...	...	...	...	...	
Refractory Brick of Suffenheim	...	...	...	572	...	...	...	...	...	...	

* Not from the same burning as was used for the other mortars of this lime.

Observations on Table IV.

This Table is very instructive in many ways; and, in particular, illustrates very fully the remarks made in the last paper on the manner of slaking, and on the strength of limes, as dependant on their composition. The analysis of all the limes experimented on is not given; but, fortunately, we have a knowledge of the composition of three of the limes, which, from their positions in the Table, are well suited as examples.

The Strasburg lime is pure carbonate of lime, containing, therefore, no clay. The Metz lime and the Obernai lime, according to M. Berthier, have the following components:—

Nature of Lime.	Lime.	Magnesia and Iron.	Silex.	Alumina.	Carbonic acid, Water & Loss.	REMARKS.
Strasburg . .	56	...	...	...	42	Assumed composition; it is stated to be pure limestone; it probably contained, however, traces of magnesia and other impurities.
Metz	44·5	6·7	5·3	1·3	42·2	
Obernai. . . .	42·2	8·0	10·5	4·3	31·0	

The silicic acid, then, without which a lime cannot make good mortar, is altogether wanting in the Strasburg lime, and in the Metz it is little more than half that which is found in the Obernai lime; the amount of iron and alumina is also apparently greatest in the last named lime, for had the magnesia been present in notable quantity the chemist would hardly have neglected to separate it from the iron. The Metz lime, according to Vicat's classification, would stand at the higher limit of the hydraulic limes of medium quality, and the Obernai lime would just fall below the class of the eminently hydraulic limes. Vicat would probably have assigned to them resistances of 110 lbs. and 150 lbs. respectively, as may be seen by interpolating between the quantities given in the Table compiled from his work (Table II.). The Strasburg lime would have fallen in the class of the rich limes, and being nearly of the same composition as chalk lime, and yielding a lime of similar quality, we may assign to it the same probable resistance, viz., 40 lbs. Roughly speaking, their resistances would be as 1, 2·75 and 3·75. Now, assuming that in Treussart's experiments, the lime, if tried without sand and with 1½ parts sand, would have exhibited a resistance greater than with two parts, in the proportion ascertained to hold good by Colonel Totten, of the United States' Engineers, as shown hereafter, and comparing the results so obtained for it with those of the Metz and Obernai limes, as shown in the three first columns of Table IV. (with 0 sand, 1½ sand, and 2 sand), we have aggregate resistance for the lime of Strasburg, 280, for that of Metz, 738, and for that of Obernai, 1178, which are as the numbers 1, 2·6 and 4·2; a result which further confirms the trustworthiness of Vicat's classification. It also illustrates the observations made in the last paper on the strength of limes as dependant on composition, and even points to the possibility of assigning to any particular lime an approximate value of its strength, from the results of analysis alone.

Referring to the three first columns of the Table last given, we find that in the case of the Strasburg, Metz, and Obernai limes, of which the composition is known, the volume of the powder produced by slaking, the volume of water required to bring the lime to a paste, and the volume of the paste produced, are each less as the quantity of clay present is greater, and this is in complete conformity with the explanation of the phenomena attending the slaking of different limes given in the last paper. By comparing the manner of slaking of the Villé, Verdt, and Altkirch limes, we may, on the principles there laid down, and by analogy, assume the Villé lime to be intermediate in composition, as regards the proportion of its argillaceous constituent, between the Strasburg and Metz limes; the Verdt lime to be intermediate between the Metz and Obernai limes; the Altkirch between the Obernai lime and the cement from the Boulogne pebbles. We might presume that they would also shew intermediate resistances, and on examination of the table we find that the presumption would be correct in two out of the four cases, but not so in the instances of the Altkirch lime and Boulogne pebbles. These discrepancies, however, are easily accounted for. General Treussart, without reference to any consideration respecting the composition of the Altkirch lime, states that it is possible that this lime is better than the experiments indicate, as it was stale when he used it. And the Boulogne pebbles were treated, as Sir Charles Pasley observed, in a manner that sufficiently shewed that the French General did not know how to use them. He endeavoured, indeed, to slake them to a powder before making them into mortar, and thereby quite ruined his cement. He should have ground them to a powder after calcination, instead of slaking them, and used them as Sheppey cement is used. Cements of such character have been shown by experiments made at Chatham on prisms of the same dimensions as were employed by General Treussart to be far superior to Obernai lime, if both the lime and cement are unmixed with sand; and cements of the quick setting description, viz., the Medina, Roman, Atkinson's, and Sheppey cements, are always used without sand when great strength is essential. The Roman cement, indeed, with one part sand, in experiments recently made at Chatham, showed a resistance of 562 lbs. after 13 months, when tested in the same manner as that adopted by General Treussart, and this is a higher result than any in his table.

The next point to be noticed is the fact that the clayey constituent can be supplied artificially, with results equal to those obtainable from the strongest hydraulic limes, but it must be remembered that the success of such mixtures is dependant on the perfect chemical action between the lime and the clay, and that chemical action ensues in such a case only at insensible distances. Very intimate admixture is hardly possible, however, on a large scale, on account of the great expense it would entail, and, therefore, these experiments hardly afford a fair criterion of what would be attained in practice. This consideration appears to have escaped General Treussart's attention. It should be remarked, before passing on, that mortars can be made which have a greater cohesive resistance to transverse strain than the ordinary Strasburg brick, and that with few exceptions, which will again be referred to, the resistance of the mortars suffered a decrease of strength with each addition of sand. It was notably so with the pure lime, and this is the description of lime which is usually considered to be most benefitted by the presence of a large proportion of it.

The results hitherto given to prove the superiority of the hydraulic over the pure limes were obtained from specimens specially prepared from experiments, and we must now show that the conclusions drawn from them are corroborated by trials of old mortars of actual constructions. There is some degree of uncertainty in such trials from the difficulty of securing specimens which have been exposed to similar conditions, and frequently external joints of the pure and feebly hydraulic limes, as may be inferred from what was said of the action of the atmosphere upon them in the first paper, attain considerable hardness, while below the surface the mortar still remains comparatively soft or friable. "There is an old priory at Dover" writes Sir Charles Pasley, "now in ruins, supposed to have been built in the reign of Henry the first, the mortar of which appeared to me to be much stronger than any I had ever seen, for I was obliged to borrow blacksmith's tools from a forge opposite, to break the surface. Afterwards I requested Colonel Arnold to have a compact piece, about 1 cubic foot, of the old masonry cut off and sent to me by coach, on receiving which I found that the inside of it had no pretensions to any very extraordinary hardness. The lime used for this mortar must probably have been Kentish Rag, as it seems superior to chalk lime." One can form, therefore, but an imperfect idea of the hardness of mortar throughout a thick wall by that of the mere external crust, as may be readily ascertained by any one who will take the trouble to scratch through it in a few buildings, and the resistance generally goes on decreasing for some little distance from the exposed surface of the joints. Since, however, in the following tables, the best of the limes were taken from the thickest walls, whatever injustice there may be from the action of the air having affected one specimen more than another, this will fall heaviest upon the hydraulic limes, the superiority of which over the pure limes is sought to be established. As it was impossible to obtain joints of brickwork of precisely similar size, it was necessary for purposes of comparison in the table following, to reduce the weight required to tear the joints asunder to the resistance per square inch. The experiments, excepting those of the first set, were made by Sergeant Hartley, under the superintendence of the writer.

TABLE V.

Showing the comparative resistance per square inch of old brickwork joints of various mortars, the bricks being torn asunder by a force acting at right angles to the joint. The lime estimated as quicklime in lump.

Nature of Lime of which the Mortar was made.	No. of Trials.	Percentage of Clay in Lime.	Parts of Sand to 1 part Lime.	Age of Mortar in Years.	Fracturing wt. per square in. in lbs.	Remarks.
White Chalk. .	6	0	*	30	3·9	From Chatham Lines. Gen. Pasley's Experiments.
Halling Grey. .	6	8	1	60	11·1	From Chatham Lines. Interior slope of St. Mary's Hornwork. Considerable spaces on the bricks without mortar; such spaces not reckoned in estimating the resistance per square inch.
Sussex Grey: probably from Lewes	3	17	1	60	9·4	From Martello Tower, Eastbourne. Mortar very badly mixed, sand good; ⅓rd of it passed through a sieve of 50 meshes to the inch.
Sussex Grey: probably from Lewes	4	17	1	60	16·1	From Martello Tower, Bexhill. Mortar better mixed; the sand, generally, fine. One-half of it passed through a sieve of 50 meshes. Some pieces as large as a small nut.

* Probably 1 sand to 1 quicklime, the quantity generally used when the Chatham Lines were erected.

Observations on Table V.

A comparison of the resistances shewn by the Sussex limes with that of the white chalk lime shews, that after long periods, the same law holds good with their mortars in actual practice as was found to obtain in experimental trials on specimens specially prepared.

The Sussex limes were of a composition which would class them amongst Vicat's hydraulic limes of a resistance of 150 lbs., and to the Halling and white chalk limes we have already assumed that he would have assigned resistances of 80 and 40 lbs. respectively. The theoretic resistances of these three descriptions of lime would therefore be as 3·7, 2, and 1. If we omit the results of the very imperfect Eastbourne mortar, they are really as 4·4, 2·9, and 1; and as 3·3, 2·9, and 1 if we take the mean of that and the Bexhill. It will be seen that the fat lime compares more unfavourably with the hydraulic limes in mortars from actual practice, than in specimens prepared on a small scale, and this result was to be expected. The pure lime mortar, owing its resistance principally to the action of the atmosphere, would not be indurated so much in a wall as in joints of pairs of bricks or in small prisms, where the amount of surface exposed as compared with bulk is much greater. The Halling lime was taken out of an 18 inch wall in which a part of the joint shewed on the face of the work. The Sussex mortars were taken from walls 6 feet thick, and no exterior joints were included. This would account for the strength of the Halling lime approaching that of the Sussex lime more closely than analogy from Vicat's experiments indicates, and making allowance for this difference of conditions, no nearer agreement could have been expected.

The low results shown in point of strength by mortars in actual buildings, as exemplified in the foregoing table, is remarkable, and will be referred to again.

The next table is given in confirmation of the above results, the trials being made by crushing instead of tearing the mortar asunder.

TABLE VI.

Shewing the resistance, to a crushing force, of 1-inch cubes of various mortars and of bricks. The lime estimated as quicklime in lumps.

Description of Lime of Mortar.	No. of Trials.	Percentage of Clay in Lime.	Proportion of Sand to 1 part of Lime.	Age in Years.	Crushing wt. in lbs.	REMARKS.
Halling Grey .	8	8	1	60	46·3	From Chatham Lines: the interior slope of St. Mary's Hornwork.
Juliers, Prussia.	1	...	3	...	47	From a bastion breached in 1860. The sand an arène of good quality: 3-16ths of it passed through a sieve of 50 meshes to the inch: the remainder of it middling and coarse grained.
Sussex Grey Lime	5	17	1	60	115·6	From Martello Tower, Bexhill.
Do. Do. . .	1	17	1	60	252	Do.: a proportion of coal mixed with the mortar.
Do. Do. . .	1	17	1	60	323	A selected specimen from Eastbourne Martello Tower.
Do. Do. . .	1	17	1	60	546	By no means a fair sample of the whole. Selected from the strongest part.
Light red brick.	...	...	...	...	562	Rennie.
Dark red brick.	...	...	...	...	807	

The experiments, except the last two, were made by Sergeant Hartley.

Observations on Table VI.

The trial by crushing seems a more uncertain mode of experiment than by a tearing force or a transverse strain, and to depend more on the size of the sand. The sample from Eastbourne selected for trial was, as stated in the column of remarks, by no means a fair sample of the mortar generally, which was so badly mixed as to render it difficult to obtain an inch cube from it. Large concretions of lime which had escaped slaking in the manipulation of the mortar were everywhere disseminated through it, and many of them were as large as almonds. These were necessarily included in the joints tried and must seriously have injured their strength, but in selecting cubes for experiment the portions where these occurred could not be rubbed down to the proper dimensions, and thus the resistance shown by the specimens which stood the pairing down, was far above the average resistance of the mortar. The Bexhill mortar though better mixed had also concretions of lime which had escaped slaking when the mortar was made, but these being in general much smaller, many of them were included in the cubes crushed as well as in the joints separated. The imperfection of the mortar, therefore, told most against the joints in the case of the Eastbourne mortar, owing to the larger size of the unmixed concretions, and to the cubes in the case of Bexhill, because the Eastbourne specimens selected, happened to be entirely free from them. The discrepancies between the results, according as the mortars were tried by a tearing or crushing force, can therefore be understood. So far, however, as comparison can fairly be made the resistances are in accordance with previous results. The Halling grey lime mortar was made with better sand than the Bexhill mortar, but on the other hand it was not quite so well mixed. On the whole, perhaps, they stood on a par as respects the effect of manipulation and sand considered together, and we can, therefore, make a tolerably just comparison between the strengths of these mortars and the strengths they might be expected to have according to Vicat's classification which, as we have seen, quite accords relatively with the results of Treussart. So far, then, as the resistances to crushing may be assumed to be in the same ratio as the resistances to transverse strain, those of the Bexhill and Halling lime mortars should be as 1·9 to 1. They are actually as 2·5 to 1.

The table, while exemplifying in another form what mortar generally is, as compared with what it may be, viz , as 1 to 3 in strength, shews that mortar can be made from good hydraulic lime which will resist crushing nearly as well as ordinary brick.

It was not possible to determine chemically the quality of the lime employed at Juliers, as the sand contains a very large proportion of clay in that condition in which it exists in hydraulic limes; that is to say, it is readily attacked by hydrochloric acid, its silex becoming soluble in potash*. There can, however, be little doubt that such sand finely ground and intimately mingled with the lime, would have given to it a great resistance, and that so far as the action between the lime and sand could take place, it counteracted the weakening influence of that portion which acted merely in a mechanical manner.

3.—The Resistance of Limes and Cements Compared.

We have now seen that there is no comparison in point of strength between the pure and good hydraulic limes, whether the trials are made on experimental joints or on those of actual constructions; and that the latter limes, when properly made into mortar, will attain to a resistance in 12 months, (even when immersed in water before they have set) superior to that of ordinary brick or soft stone.

We have next to shew that the hydraulic limes, superior as they are to the pure limes, are far inferior to the cements, and that although the older quick setting cements, such as Sir Charles Pasley made, and such as we still obtain from the argillaceous nodules of the London clay (the Roman and Sheppey cements) and from some beds of the lias formation, are so much injured by the addition of sand as to render their employment very expensive, yet that there are now in use cements which will carry a large proportion of sand, and attain, notwithstanding, a greater resistance than the best hydraulic limes are capable of without any.

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* See page 22.

The following table is compiled from Table IV of Pasley's work on Limes, Water Cements, &c., and shews the superiority of his own cement after a few days, especially without sand, to old chalk lime mortar. The experiments were made by separating bricks united by cement or lime, the cement joints having been made for the experiments, and the mortar joints obtained from brickwork by cutting out masses from it.

TABLE VII.

Showing the comparative strength of joints of brickwork of pure cement, cement mixed with sand, and of common chalk lime mortar.

Nature of Mortar.	No. of Trials.	Age in Years or Days.	Fracturing wt. in lbs. on an area of 40 sq. in.	REMARKS.
Pure or nett cement.	3	days 11 to 17	1092	The sectional area experimented upon was the same in each case, viz., 40 square inches.
Cement and sand: equal parts . . .	3	11 to 17	225	
Chalk Lime Mortar.	6	yrs. 30	155	

Observations on Table VII.

Sir Charles Pasley conceives it probable that if the cement joint had been older, the mortar of cement and sand would have exceeded the strength of the chalk lime in a five-fold ratio, and he remarks that many of the joints of the chalk lime separated merely on being handled without any weights being applied to them at all. Now since the joints which broke in handling were probably weaker than those which underwent the test of being weighted, it is reasonable to suppose that the above is a high average for chalk lime, and the chalk lime mortar after 30 years, had not more than $\frac{1}{7}$ of the strength of Sir Charles Pasley's cement, used nett, after 11 days. In the next table we shall find a comparison between this cement and cements of recent manufacture, and we shall thus with the help of the two tables be enabled to form an idea of the difference in strength between works executed in pure lime mortar and cement mortar such as is now made.

All the results compared in Table VIII were made in a similar manner by the rupture of prisms 2 inches square in section and 3 inches between the points of support, the weight being suspended over their centres by means of a stirrup as before.

The recent experiments made at Chatham were directed by Captain Schaw assisted by Lieutenant Moncrieff, I.E. The prisms were moulded carefully by Corporal Gray, R.E.

TABLE VIII.

Showing the comparative mean resistance in lbs. of prisms of certain mortars and of bricks to transverse strain, the prisms being 3 inches between the points of support, 2 inches square in section, and loaded at their centres:—

Name of Cement or Lime used, Brick or Stone.	No. of Trials.	Age when immersed.	Age when fractured.	Composition of Mortar. The Lime or Cement measured in unslaked powder.					REMARKS.
				Nett Cement, Lime, or Brick.	1 Sand, 1 Cement or Lime.	2 Sand, 1 Cement or Lime.	3 Sand, 1 Cement or Lime.	4 Sand, 1 Cement or Lime.	Names of Manufacturers and Experimenters.
Roman cement . . .	5	Not immersed.	11 days	400	279	178	154	149	From Messrs. Francis. Captain Schaw.
Portland ditto . . .	5	do.	30 „	...	529	538	323	158	Messrs. White's Portland cement.
Scott's ditto . . .	5	do.	do.	...	382	333	263	242	Made by Messrs. Lee from feebly hydraulic chalk lime.
Ditto ditto . . .	5	do.	13 months	...	780	650	410	...	
Roman cement . . .	5	do.	do.	...	562	214	102	...	From Messrs. Francis.
Lias lime	5	do.	do.	...	158	...	...	...	From Messrs. Greaves.
*Halling lime	2	do.	433 days	...	...	...	141	...	Pasley.
*Rose-hill	2	do.	342 „	...	199		...	...	
*Chalk lime.	2	do.	396 „	...	...	...	104		Pasley, 3½ sand used.
†Obernai lime	...	do.	12 months	323	...	260	154	...	The mean of Gen. Treussart's results, Table XXXVI., with his strongest lime exposed to air.
Bath stone	5	...	...	666	...	...	...	...	Pasley.
Well burned bricks.	5	...	...	752	...	...	...	...	
Interior bricks . . .	6	...	...	329	...	...	...	...	
Common brick of Strasburg. . . .	...	...	...	462	...	...	...	...	Treussart.
Refractory bricks of Suffenheim .	...	...	...	572	...	...	...	...	

* Sir Charles Pasley measured his lime in paste, but the bulk of the paste may be assumed to be equal to the unslaked lime in powder without material error with the limes he used, as shown by his own experiments.

† General Treussart measured the lime in paste, and 1 part of Obernai quicklime in powder produced 2 parts of slaked powder which formed 1 of paste. See Table IV. above.

Observations on Table VIII.

It will be observed from this table that there is no comparison between the cements and the best water limes of this country, or of those that General Treussart experimented with. The Roman cement with 1 part sand, possesses after 12 or 13 months, double the strength of the Obernai lime with 2 parts, and if the proportion of sand is increased, though the Roman rapidly loses its resistance, yet other cements still retain their superiority. It is fair, however, to call attention to the results obtained by a specimen of Obernai lime burned grey, and immersed in water after 12 hours, which results were given in Table IV. above.

The Portland cement with 3 parts of sand, the Scott's with 2 parts, were, after 1 month, stronger than inferior bricks. After 12 months, the Scott's cement with 1 part of sand, was stronger than well burned bricks, with 2 parts superior to the mean of inferior and well burned bricks, and nearly as strong as Bath stone ; with 3 parts of sand, it was considerably stronger than inferior bricks. The Portland cement prisms with 1, 2, and 3 parts sand, after 12 months were so strong that a few of them, only, broke with 1100 lbs. With neither of these cements was the loss in strength, occasioned by an increase of sand, at all comparable with what occurred in the case of the Roman cement, which was the sort of cement known to Sir Charles Pasley, and imitated by him in his artificial compounds.

TABLE IX.

Showing the comparative mean resistance to a tearing force per square inch of the Mortars in the preceding Table. The forces estimated by fracturing joints of brickwork:—

Names of Cement.	No. of Trials.	Age of Joint when fractured.	Fracturing Weight of the Joints in lbs., the Lime or Cement measured in unslaked powder.						Remarks.
			To 1 part Cement or Lime.						
			0 Sand.	1 Sand.	2 Sand.	3 Sand.	4 Sand.	5 Sand.	
Lee's Portland cement. .	5	11 days	..	70·1	53·3	..	..	..	Observers: Captain Schaw, Lieutenant Moncrieff, and, in a few instances, Captain Scott.
White's Portland cement.	5	11 ,,	..	50·4	43·3	30·3	42·0	23·8	
Scott's cement	15	11 ,,	29·2	28·6	30·8	32·8	28·1	19·4	
Roman cement	10	11 ,,	40·0	27·9	17·8	15·4	14·9	7·3	
White's Portland cement.	5	30 ,,	..	..	66·7	50·5	52·1	35·6	
Scott's cement	5	30 ,,	52·1	51·4	52·7	52·8	33·1	39·8	
Roman cement	5	30 ,,	49·9	42·4	23·6	..	..	..	
Lias lime	15	30 ,,	12·4	..	..	..	..	..	
Portland cement	15	12 months	..	upwards of 110			..	..	The bricks always fractured.
Scott's cement	15	12 ,,	..	upwards of 110			..	..	The bricks generally fractured.
Pasley's cement	3	11 to 17 days	27·4	5·6	..	..	..	..	Table IV.. from } Pasley on Limes and Cements.
Pasley's cement	9	70 days	125·0	..	..	..	..	..	Remarks on Table IV., from
White chalk lime	6	30 years	..	3·87	..	..	..	..	Table IV., from
Halling lime	6	60 ,,	..	11·1	..	..	..	..	From Table V., above.
Sussex lime: Eastbourne Martello Tower	3	do.	..	9·4	..	..	..	..	
Sussex lime: Bexhill Martello Tower	14	do.	..	16·1	..	..	..	..	

Observations on Table IX.

The superiority of the cement mortar to the lime mortar, manifests itself quite as remarkably when tested by a tearing force as by a transverse strain. The best specimen of Bexhill mortar with one part of sand, had not $\frac{1}{3}$ of the strength of the Portland or the Scott's cement, mixed with 3 parts of sand, after 30 days. Unfortunately, before making the experiments at the end of one year, the pairs of bricks to be torn asunder had to be removed from the Engineer Yard to the Barracks. This was done under the superintendence of a Sergeant, who, in the meantime, was sent to the Cape, and carried his memoranda with him. Consequently there was a little uncertainty in deciding, in some cases, on the quantity of sand which had been used, but it was very clear that the weakest of the two cements, viz., the Scott's, with 3 parts of sand, had generally a greater resistance than the bricks, and must have exceeded 110 lbs. It appears also that this cement with 3 parts of sand, after 12 months, is more than 6 times as strong as the Sussex mortar of the Bexhill Tower after 60 years, and about 12 times as strong as that of the Eastbourne Tower after the same period.

TABLE X.

Showing the weights required to crush inch cubes of Cement and Lime Mortars, &c. :—

Name of Cement or Substance.	No. of Trials.	Age of Cement.	Resistance to crushing in lbs. The Limes and Cement measured in unslaked powder.			Bricks.	Remarks.	
			0 Sand, 1 Cement or Lime.	1 Sand, 1 Cement or Lime.	3 Sand, 1 Cement or Lime.			
Juliers mortar.	1	..	..	..	47	..		Experiments made by Sergeant Hartley.
Halling lime mortar.	8	60 years	46·25	..	..	..	From Table VI.	
Bexhill	5	do.	..	115·6	..	..		
Eastbourne.	2	do.	..	434·0	..	..	A high average, for reasons given in Observations on Table VI.	
Scott's cement	5	9 months	1913	..	..	..	Prepared from Warwickshire Lias Lime.	
Ditto ditto	1	do.	..	..	300	..		
Ditto ditto	6	do.	1568	..	..	..	Prepared from Barrow lias lime.	
Ditto ditto *	3	do.	1715	..	..	..	Prepared from Plymouth hydraulic lime.	
Ditto ditto	2	do.	1264	..	..	..	Prepared from South Wales lias lime.	
Eastbourne brick, 1 sample	..	..	..	..	..	1019	Well burned.	
Ditto ditto 2 sample	..	..	..	..	..	1677	Very hard burned.	
Ditto ditto 3 sample	..	..	..	..	..	1806	Vitrified.	
Light red brick	..	..	..	..	..	562	Rennie's Experiments.	
Dark red brick	..	..	..	..	..	807		

* In this case the prisms were 1 inch high, and 1 inch by ¾ inch in section. Their mean breaking weight was ¾ of that in the Table.

Observations on Table X.

It is only necessary to call attention to the great resistance of the cements as compared with the limes by this mode of trial also, and to point out that the cement, when used without sand, resisted the compressive force better than a vitrified brick. In the set of experiments with cement made from Barrow lime, where the mean crushing weight on six experiments averaged 1568 lbs., the whole six, excepting in one instance, yielded as soon as 1600 lbs. were put on the scale. The specimens of the Lias lime cements set in water, and remained immersed up to the time of trial, excepting for a few days, during which the cubes were being pared down to the proper dimension of 1 inch side. The Plymouth lime cement remained buried in moist earth for the same period. Attention may be called, in passing, to the fact, that the loss of strength, to resist a crushing force increases very rapidly with the quantity of sand employed, when the specimen is free to give laterally. It seems probable, however, that such crushing would not take place in brickwork when the base of the layer as compared with its height is very great.

It was stated above that the bulk of paste of lime produced from limestones of different densities, but of similar chemical composition, is proportional to their specific gravities when the mode of treatment is in all respects the same, and that therefore the original density of a limestone has no necessary connection with the hardness of the resulting mortar. The experiments made by Colonel Harness, and alluded to in a note at page 24, together with experiments made by Sir C. Pasley and Mr. Cahill, are given in the next table in proof of this; but it should be understood, that unless the mode of treatment in burning, and in slaking be identical, the quantity of paste produced, even from the same lime, will perhaps vary widely. The bulk of the paste depends principally on the degree of heat generated in the process of slaking, and this is affected by the freshness of the lime and the quantity operated upon; and also if the lime is hydraulic, by the temperature at which it has been calcined. With limes of different density, all other things being equal, the densest lime may be expected to give the most bulky powder in proportion to the weight operated on; for the near proximity of the particles, by assisting the chemical action, throws abroad the lime more perfectly, and reduces it to a finer powder, which again produces a bulkier paste. This is a good reason for a contractor preferring a dense limestone, but does not appear to favour the notion that such a stone will yield the hardest mortar. The volumes of the paste would be proportional nearly to the volumes of slaked lime powders.

TABLE XI.

Description of Lime.	Weight of a cubic foot of Limestone, in lbs.	Weight in lbs. of a cubic foot of lime measured by the yard from the kiln.	Volume in cubic feet of slaked lime powder produced from 1 cubic foot of limestone.	Relative volume of slaked lime powder produced from equal weights of limestone.	Remarks.
Chalk, White .	90	...	1·79	·92	Sir Charles Pasley.
Plymouth Limestone	160	...	3·33	·96	
Bermuda Soft Limestone . .	92·25	...	2 nearly	1·0	Col. Harness *With some unslaked lumps removed 1·0
Do. hard do.	164·4	...	3	·84*	
Lias Limestone, Lyme Regis .	...	54·4	1·9	...	Mr. Cahill. These limes containing clay are of course not comparable with the pure limes above. The Lias Lime from Lyme Regis contains on an average 12½ per cent of clay—The Keynsham Lias 10 per cent.—H. S.
Do. Keynsham.	...	62·3	2·82	...	

It has, it is hoped, been proved that the observations made in the first part of this paper are borne out by actual experiment, whether the trial is made on specimens specially prepared, or on samples taken from old brickwork constructions—whether it is made by a tearing, a breaking, or a crushing force. The pure limes cannot compare with the hydraulic limes, and these again are far inferior to the cements. Unless there is some serious objection of manipulation to the practice which gives the best results, the question is reduced, for heavy brickwork and masonry, to one of economy.

4.—On the Action of Sand in Mortars.

It was stated in the early part of this paper that the prevalent ideas on the action of sand in mortars used in masonry, as a cementing material, were erroneous; and an attempt will now be made to prove the truth of this statement. It may be difficult at once to credit the assertion that the building world can so long have been at fault upon a point of so much importance; but it is believed that a consideration of the various opinions that have been expressed, and the results of experiments made to ascertain the action of sand, must lead to the conclusion that the assertion is correct.

It was probably very soon noticed that pure lime mortar, if used as a stucco without a sufficiency of sand to prevent shrinkage, failed through the cracks and fissures which took place in it; and then the step was easy to the persuasion that, under all circumstances, sand should be used with mortar to make strong work.

When once this conclusion was accepted, no attempt was made to verify its accuracy; and the whole attention of those interested in building was turned to the discovery of the way in which the assumed fact might be accounted for. As, however, this had no existence, it is scarcely matter for astonishment that there should be wide differences in the proportion of sand supposed, by different writers, to be the best—that there should be little agreement in their modes of accounting for the supposed increase of resistance due to its action—and that, finally, it should be left to the workman to do pretty much as he pleased in compounding his mortars.

The question of the effect of sand is, however, one of so much importance to the Military Engineer, whose constructions are to have the strength necessary, not only to resist the action of the atmosphere, and the dead pressures arising from the weight of structures, but also to support as long as possible the concussions of artillery fire, that he cannot afford to remain in error on the point. The matter will therefore be discussed at some length, and the opinions of writers, and their experiments will be given in such a form as to allow the reader to form his own judgment; and we will commence with the earliest writer, who attempted to account for the setting of mixtures of lime and sand.

Vitruvius states that "when the lime is slaked, it is necessary to mix three parts of sand, if the sand is fossil" (by which term he means pit), "with one part of lime; and if the sand is river sand, to add two parts of it to one of lime." "Such," he says, "are the proportions best suited for making mortar," and he endeavours to account for the fact of this mixture hardening, in the following manner:—"The weight of the lime, after calcination, is diminished about $\frac{1}{3}$, by the evaporation of the watery parts; from this it results that the pores, being empty, are better fitted than before to receive the admixture of sand, and to unite strongly with the blocks of stone to form solid masonry." *

Perrault † endeavours to prove Vitruvius was correct, and that his explanation coincided with that of the chemists of his time. These believed that the lime stone having lost, by the action of the fire, all the volatile parts, which were the cause of its hardness, is left full of empty pores, formed by an extremely dry and arid matter, which absorbs with avidity the humid portions of the atmosphere; but as these cannot restore to it the components which it loses by calcination, they reduce it to an impalpable powder; and it is this avidity of the lime which produces its causticity. When this property acts on the sand and on the stones, it brings out of them, with time, a part of the sulphurous and volatile salts which they contain, and produces between them, so strong an adhesion as to form a solid and hard body. They thought, further, that the sand loses a portion of its hardness, and that the lime profits by this loss, and thus a mutual disposition to unite strongly is developed; consequently, when an attempt is made, after some time, to separate the stones of masonry built with good mortar, the mortar is observed to adhere with great force to their surfaces.

It is evident that so far no sufficient reason has been given for the supposed effect of sand. Its beneficial action being assumed, fanciful theories are sought in explanation of it.

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* Vitruvius. Book II., chap. V.

† Rondelet, L'art de bâtir, Livre 2, sect. 1.

Macquer says,[*] that the cause of the action of mortar may be deduced naturally from the properties of the lime, and it is especially owing to the fine division of its particles, when it has been slaked. This extreme state of division, which reduces the particles almost entirely to surfaces, enables them to attach themselves very closely to the superficies of the sand or the cement,[†] and to adhere with a force proportional to the accuracy and intimacy of contact.

With reference to the question why paste of lime, without sand, does not reach the consistency and hardness of mortar (for he, like his predecessors, takes the beneficial action of sand for granted), Macquer supposes that, generally, the particles of slaked lime adhere more closely to hard bodies than to each other, on account of the great quantity of water united to them, which prevents their coming so closely into contact as they do with sand or cement, for these substances, by absorbing a portion of the water of the slaked lime, facilitate the drying and adhesion.

Though this reasoning is, on the whole perhaps, better than that of previous writers on the subject, the questions of adhesion and cohesion being considered, and arguments worth weighing at least, brought forward in support of the superiority of the former, it is hardly necessary to say that silicious sand cannot absorb a perceptible quantity of water.

Belidor prescribes 2 or 1½ measures of sand to 1 measure of lime paste; or, if the lime be very fat, 3 measures of sand to 1 of lime paste;[‡] this amounts to 1 or ¾ sand to 1 measure of slaked lime in powder for ordinary cases; or 1½ sand to 1 part of lime powder, if the lime is very fat.[§]

Rondelet, after carefully considering the theories of preceding authors, determines that no precise rule can be laid down for the proper proportion of lime and sand, and appears to have arrived at pretty much the same conclusion as Belidor. He says, "that there is quick lime, such as that of Melun, which absorbs, in slaking, 2½ times its weight of water, to form a paste moderately fluid, such as is required for ordinary mortar, without being obliged to add more water."

"There may be found other lime which, in order to form a paste of equal consistency, consumes only a quantity of water equal to its own weight. It has been found, from numerous experiments, that in order to make good mortar with the first of these pastes, it is necessary to mix 3 parts of river sand with 1½ parts of lime"—(or equal parts of sand and lime, if the lime is measured in powder), "and, in making use of the second paste, 2 parts are necessary for 3 parts of the same sand. These two mortars, when equally well mixed, acquire, with time, the same consistence."

"It is necessary to observe," he continues, "that, in the first mortar, the quantity of lime in paste is ½ the sand, and in the second ⅔; however, since

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[*] Rondelet, L'art de bâtir, Livre II., sect. 1.

[†] Calcined clay, puzzuolana, &c., are here meant by this term.—H. S.

[‡] This information is also obtained from Rondelet's work.—H. S.

[§] It is necessary, of course, to ascertain always in what way the lime is measured. It is still a matter of dispute, whether Vitruvius meant lime in paste or slaked lime powder in the paragraph quoted above. It is believed by Smeaton, and Mr. Newton, one of his translators, that he meant lime in slaked powder.

Vitruvius, all who have written on the art of building, have repeated that, in order to make good mortar, it is sufficient to mix 1 part of slaked lime with 2 parts of river sand; but it is requisite to suppose a lime of superior quality to that of Melun, which, however, is considered very good. As to the quantity of quicklime in these two mortars, I found that in the first it is only ⅐ of the sand, whilst in the second it is ⅓ of it. It is this last proportion which M. de la Faye prescribes. In order, in all cases, to make a proper mixture, a certain amount of experience is required to judge of the degree of consistence which well slaked lime, and mortar sufficiently mixed, should have. It is this degree which determines the quantity of water for slaking the lime, and the quantity of sand necessary to make good mortar."

Rondelet here takes up new grounds. Assuming, like his predecessors, that sand acts beneficially on mortars, he considers that they were wrong in prescribing the same dose of it for all limes, without regard to quality; and that the object to be attained is a compound which will have that degree of plasticity which a skilful workman finds to suit him best. He goes on to say, indeed, "In all the parts of France and Italy through which I have travelled, I have questioned those workmen who appeared most intelligent. I have found that their knowledge reduces itself to a practical knowledge which usage and experience render sufficiently sure." . . . . "A workman, who, by a long experience, is accustomed to judge if the mortar is fat enough, enough worked, and if it has the consistence it ought to have, is rarely deceived; he beats and mixes the different ingredients of which it is composed, until he has hit off the point he aims at,"* which, in these days, at least, is that point which will give the least trouble.

Dr. Bry Higgins, who wrote 20 years before Rondelet, prescribes, that no more than 1 part of lime to 7 of coarse sand, ought to be used in mortar to dry quickly; and less lime may not be used, because it does not render the mass sufficiently plastic for building or incrustation.† He subsequently states that this is the best proportion, whether the mortar is to be quickly dried or not.‡ Dr. Higgins measured his ingredients by weight; and, according to Smeaton's calculation, Thames sand weighs 4½ § times as heavy as the slaked powder of common lime; the above proportion, therefore, is somewhat under 1½ parts sand to 1 of lime, in slaked powder, or 3 parts sand to 1 of lime, measured in paste.

The discrepancy between Higgins' statement and Rondelet's, as to the amount of sand which gives the best consistence for working, is to be accounted for in this way:—Dr. Higgins, though concluding the above proportions to be the best for building purposes generally, arrived at them by experiments made with reference to stuccoing, for which purpose freedom from shrinkage is a more valuable property than freedom in working. He decided, in fact, on the most *plastic* composition which did not crack in drying.

Smeaton, whose opinions, perhaps, will carry more weight than those of any of the writers quoted, says—"The use of sand in mortar, so far as I have been able to observe, is twofold: 1st, to render the composition harder; and 2nd, to increase it in quantity by a material that, in most situations, is of far less expense, bulk for bulk, than lime. As there is no apparent change in the sand, by the admixture of the lime, the sand seems only to render the composition harder, by itself being a harder body; for the best sand, being small fragments of flint, crystal, quartz, &c., is much harder than any body we know of, that can be formed of lime only, and which, in paste, is to be considered as a cement to the harder materials, and, therefore, composes a harder body; for the same reason that, if we had nothing naturally but lime as a cement, and should build a wall with flints, crystals, or rough stones, cemented therewith, this wall would be far harder than if built with lime alone."

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* Rondelet, L'art de bâtir. Livre II., sect. 1., art. 1 and 4.

† Higgins on Calcareous Cements. Sect. VII., p. 48.

‡ Higgins on Calcareous Cements. Sect. VII., p. 49.

§ Smeaton's Narrative, p. 119.

Smeaton did not, however, apparently arrive at this conclusion from comparative experiments on resistance of different mixtures, for, in the next paragragh, he continues:—"The *experience of ages has shown** that a considerable quantity of sand and other matter may be introduced with advantage in the making of mortar, but the proportion has never been agreed in; yet, from *common* experience, it appears that there is scarcely any lime, but what, if well burnt and beaten, a load or measure of lime will take two loads or measures of sand; that is, the quantity of sand that can be introduced into its composition may equal the lime in powder." . . . "Finding this idea so far to answer, not only in experiment, but my expectations satisfied in works at large, I was induced to try whether lime would not bear a still greater addition of sand; and I soon found that it would, *with good beating*, take in, for every 2 measures of slaked lime, 1 measure of tarras and 3 of clean sand." . . . "Still pursuing the same line of experiment, to see how far this matter could be carried, it appeared that even yet a greater proportion of sand could be introduced; but, to bring it to a proper *consistency and toughness*, so as to be a good cement to large stones, I found it needed so much more beating that the labour became in most cases, of more value than the saving of the materials."† The proportion last employed, he adds, in a foot note, agrees, allowing for the tarras, with the greatest mixture of sand and lime of Dr. Higgins, which was scarcely 2 of sand to 1 of lime powder.

In the same note Smeaton states, "I have long since found the necessity of forming a composition of fine and coarse sand for mortar, unless the sand is naturally so mixed, as appears by the first note on § 200; for as the lime will receive the most sand in that way, *without losing its plasticity*, it will *of consequence* make the hardest and firmest mortar."

In concluding that those mortars must of necessity be the best, which have as much sand as they can carry without losing the toughness and plasticity which the workman has reason to prefer, Smeaton must either have lost sight of the influence which the relative forces of adhesion of the lime paste to the sand, and of the cohesion of the particles of paste amongst themselves, must have, *after setting*, upon the resistance of the compound; or he must have assumed that the former was of necessity the greater, and that each grain of sand would be perfectly coated. Probably, no doubt of the beneficial effect of a certain quantity of sand arose in his mind, and he adopted the view of the question in vogue in his day; his experiments, therefore, had reference rather to a point of manipulation than of principle; he wished to ascertain how far extra beating and perfect amalgamation would counteract what was considered an extra dose of sand.

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* The Italics in this and the following paragraphs are not used in the original.

† Smeaton's Narrative of the Eddystone Lighthouse, p.p. 119 and 120.

Vicat, although doubtless led by his experiments to very correct results on the comparative resistances of mortars of different limes, yet carried on his trials generally in so unsatisfactory a manner, that General Sir Charles Pasley was led to regret that he could not attach to them that confidence which the author places in them.* In many instances he adopts views on small differences of resistance, which further experiments would have caused to disappear. His opinions, therefore, should not have great weight given them, when unconfirmed by other observers. He draws distinctions between the composition that should be given to mortars—according as they are made from fat or hydraulic lime—as they are slaked by the ordinary method, by immersion or spontaneously—and according as they are intended for exposure to weather, to damp, or to vicissitudes of heat and cold. For fat lime, slaked in the ordinary method to be exposed to air, he gives the preference for strength, and resistance to frost, to 240 parts of sand to 100 of stiff paste of lime; for exposure to damp, he states that fat limes so slaked lose in resistance, if more than 50 parts of sand to 100 of paste are used; for covered parts of buildings he puts the maximum limit of sand at 55 parts to 100 of lime in paste. He also asserts that the "intervention of pure sand does not tend, as was before believed, to augment the cohesion of which every kind of lime indifferently is susceptible; but it is *injurious* to rich limes, very serviceable to the hydraulic and eminently hydraulic limes, and is neither beneficial nor injurious to the intermediate kinds."†

It would have been considered unnecessary to allude to these contradictory statements on the subject had not Vicat's reputation been so great, and use been made of some portions of his researches to aid in establishing the opinions advocated in this paper on other points.

Colonel Raucourt de Charleville, an admirer of Vicat, and who was at one time employed by the Emperor of Russia on account of his experience in mortars, enlarges upon, and illustrates, after a Frenchman's manner, the idea already quoted from Smeaton's work on the cause of the hardness imparted by sand to mortars. He states that "Whenever the sand is harder than the cement,‡ as there exists between them a reciprocal action, the more sand a mortar contains the harder it will be; that, in consequence, in order to obtain a mortar of maximum resistance, it is necessary—1st, that the sand be of such a size as to yield the greatest mass possible in a given volume; 2nd, that the grains of sand be arranged one against another; 3rd, that the cement to unite them only fills the intervals which separate the grains. Every addition beyond this will only do harm, just as abundance of felspar or mica injures the resistance of granites, which is only a particular case of this general principle:—that the resistance of a mixture of substances depends chiefly on the resistance of the component of which there is most; whence it results, that the minimum of cement, or enveloping parts which can be added to sand, or the parts enveloped, to make the best mortar, is decided by the measure of the voids of the sand." Then follows an important modification, which, indeed, appears to upset his illustration, if not his theory.—" With porous sands, the proportion of lime should be the same as for cement. With smooth sands, which cannot attach themselves mechanically to the lime, and which act on it, as on the clays, in dividing them, the best plan would be *not* to add sand; but one does it for economy's sake, and especially because the employment of nett lime is almost impossible on account of shrinkage." He recognizes, then, the necessity that there shall be either a strong mechanical or a chemical adhesion to the sand, to enable the sand to impart strength to mortar; but, if hydraulic limes have an action on sand, they have it by means of the free lime they contain, and pure lime would be more effective; next, the felspar has no chemical action upon quartz, and in the strongest granite the particles of quartz are quite as smooth as surfaces of sharp river sand; the granite illustration, therefore, of the general principle should better apply to the fat than to the hydraulic limes, and it is peculiarly to the fat limes that the common notion of just filling the voids of the sand is held to apply. Hydraulic limes are supposed to require somewhat less, and the theoretic reason given for this difference is that they already contain matter which is not calcareous; practically less is used because they do not, as Rondelet found, produce so fat a paste, and will not carry so much sand without working short.

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* Pasley on Limes and Cements. App. LXXXIII.

† Vicat on Cements. Chap. XI. XII. and XIII.

‡ By the term cement, the author means any calcareous substance containing clay, and, therefore, includes what are usually termed hydraulic limes.

The work of Sir Charles Pasley illustrates this point, and affords a striking example of the influence which a long received opinion may have over minds most given to investigation and experiment, and the least disposed to receive matters on trust.—" We found," he says, " by repeated experiments at Chatham, that one cubic foot of Halling lime weighed nearly the same when fresh from the kiln; and, by the gradual addition of water, that it dilated to the same increased bulk in the state of quick lime powder, but when worked up into mortar, *not too short for use*, that it would not bear quite so large a proportion of sand as the common chalk lime had done. This experiment, leading to a result in opposition to a common opinion amongst the builders of the metropolis, which is, that the Dorking and Halling limes, as being stronger limes, will, when made into mortar, bear more sand than common chalk lime, I was induced to examine the principle upon which they found this opinion, which, on consideration, appears to me to be erroneous, because these two limes are undoubtedly in an intermediate state between pure lime, which is the weakest, and the water cements, which are the strongest, of all calcareous cements; and everyone will acknowledge that the proportion of sand which will make good mortar with chalk lime would entirely ruin cement, which is scarcely capable of bearing one-third of that quantity. Hence, it follows, that the hydraulic limes ought not to admit of so much sand as chalk, but that they will bear more than cement without being injured." *

The reasons for the London builders' notions on the subject can be accounted for by the fact of the misnomer of grey chalk lime already alluded to, for stone limes slake to a bulkier paste than chalk limes as they contain more lime in a given measure; tunnel burned lime, also, such as the white chalk, contains more core than the flare-burned grey lime; but it must at once be admitted, that if the proportion of sand, which will make good mortar with chalk lime, will *not* ruin *all* cements of the same natural character as those to which Sir Charles Pasley alludes, his whole argument falls to the ground. A reference to Table XVIII. of this paper will at once decide the point for those who are not already acquainted either with the Portland cement or that of the writer's invention; and the practical builder has no need of any further proof than the former cement daily gives him. He may be in doubt whether the sand has a beneficial effect on its strength, or otherwise; but he will have no hesitation in denying Sir Charles Pasley's supposition that even a large proportion *spoils* it.

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* Pasley on Limes and Cements, Art. 25. The italics in this and the following paragraphs are not in the original.

"We have since ascertained," he continues in the following paragraph to that quoted, "that 1 cubic foot of blue lias lime from the kiln, mixed with 2 cubic feet of sand" (or 1·7 of slaked lime in powder, according to his own experiments, to 2 cubic feet of sand), "and about $\frac{3}{4}$ of a cubic foot of water, made mortar fit for use, but which could not have borne more sand without becoming *too short.*" And he states that this opinion, first formed by him "from analogy, and in consideration of the blue lias approaching very nearly to a water cement, proved, on due enquiry, to be borne out by, and exactly conformable to, the practice of the masons of Lyme Regis," though Captain Savage, of the Royal Engineers, who was employed there, assured him that a smaller proportion made better mortar. After further experiments, he writes, "contrary to our former opinion, which was chiefly derived from the *apparent shortness of the mortar*, made with 3 measures of sand to 1 of lime, which mode of judging by the eye alone was mere guess work, compared with those experiments in Table XIII," by which it has been so far disproved, as to show "that, although a mixture of 2 of sand to 1 of blue lias still appears to make the best mortar, yet 3 to 1 does *not spoil* it, as we formerly believed." * Here we have the old notion concerning the intimate connection between a free working plasticity and maximum strength still clinging so strongly to Sir Charles's mind, that he cannot divest himself of it, and thinks his eye must have been deceived in his earlier rough experiments. Unfortunately, however, for such a theory, the Portland cement—the strongest binding calcareous material known—works short even without sand, and neither it, nor the Scott's cement can be called spoiled in dry work with as much as four parts of sand, as will hereafter appear in Table XVIII.

It is to be observed that the period allowed by Sir Charles Pasley for the hardening of his mortars, made with a view of determining the best proportion of sand, was insufficient for anything like *setting* to take place, and if the plan, adopted by Colonel Totten in his later experiments, be founded on a right principle, Sir Charles Pasley's results do not strengthen his views, but the reverse. Colonel Totten's method in these experiments, was to take the maximum result of each set of experiments to indicate the true resistance of the mortar, on the principle that there are several causes to make a prism (and the same reasoning would apply to a joint) weaker than it should be, and few or none to make it stronger. And this appears to be a just manner of considering the question so long as it is one of the effect of more or less of one or other of two ingredients, but it would not be so in a comparison of two kinds of lime or cement, since there might be an irregularity of action inherent in the nature of one of them tending to produce weakness.

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* Pasley on Limes and Cements, Art. 279.

Arranged, by this rule, Sir Charles Pasley's experiment gives the results shown in Tables XII. and XIII. following.

TABLE XII.*

Comparative resistance of various lime mortar prisms, 2 inches square in section, and 3 inches between the points of support, to a transverse strain, applied at their centres:—

Lime measured in Paste.	Age in Days.	Maximum Resistance in lbs. of Mortars.			Remarks.
		Lime 1 Sand 0	Lime 1 Sand 2	Lime 1 Sand 3	
Blue Lias Lime	14 to 19	328	209	161	On 6, 5, and 5 trials respectively.
Halling Lime	14 to 15	57	127	98	On 8, 8, and 6 trials respectively.
Chalk Lime	14 to 15	63	97	85	On 3, 5, and 5 trials respectively.
Mean effect of sand on the limes taken in the aggregate	..	112	108	86	On 17, 18, and 16 trials do.

TABLE XIII.†

Showing the maximum resistance of joints of mortar of various limes between pairs of bricks, united by their largest surfaces, to a force tending to pull them asunder. The Table from which this is compiled is termed by General Pasley one of "Comparative adhesiveness:"—

Nature of Lime measured in Paste.	Age in Days.	Maximum Resistance in lbs. of Mortars.			Remarks.
		Lime 1 Sand 0	Lime 1 Sand 2	Lime 1 Sand 3	
Blue Lias...... ...	15 to 16	655	534	557	On 5 trials in each case.
Halling Lime	15 to 16	442	377	379	Do. Do.
Chalk Lime	15 to 16	400	386	363	Do. Do.
Mean effect of sand on the limes taken in the aggregate	..	499	432	433	On 15 trials with each proportion of Sand.

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* Pasley on Limes and Cements, Table XII.

† Pasley on Limes and Cements, Table XIII.

The table given from Colonel Treussart's work in the first part of this paper was drawn up with the object of showing certain relations between the composition of limes and the resistances of which they are capable, and it did not include a series of experiments made with a view to determine the best proportion of sand for mortars, nor many others calculated to throw light on the subject. These are too valuable to be omitted, and will now be given. Treussart, like other builders of his time, had a firm persuasion that the effect of sand is beneficial, as will appear from the following extracts from his work, and evidently he did not entirely relinquish the idea, though his experiments showed it to be erroneous. "I regret," he says with reference to the first set of experiments which he gives, "not being prepared for this superiority of the hydrate over mortars, but I was far from expecting it; otherwise after having made the experiments with the limes alone, I should have made mortars, by adding successively $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, &c., of sand, so as to judge better of the effect of sand; but it was only on breaking the mortars at the end of the year that I could know the effect, and I have often, on such occasions, obtained results that surprised me."

In his observations on the results of experiments given in Table XXXVI. of his work and made with a view of determining the effect of sand, he writes, alluding to Nos. 7 to 11 of his Table. "The best result corresponds to 1 part of lime in paste to 1 of sand; it is possible that a smaller proportion of sand would be still better, for we see that No. 19, which is lime reduced to paste without any sand, gave a stronger result; but as No. 19 was made of lime of another burning, I placed it at the end of the table that it might not lead to false conclusions. I did not anticipate that there may be hydraulic limes which will support only a very small quantity of sand; otherwise I should have commenced the series with a much smaller proportion." . . . "When I saw the hardness of this hydrate (No 19 above alluded to) my intention was to make similar trials with other limes, in order to know if the sand added in the composition of mortars, always, or only with some peculiar limes, diminished the resistance of hydrates; but I was obliged to quit Strasburg before it was in my power to make the essays."

It is quite evident that Treussart was backward to be persuaded. The testimony of his own results was however most decisive as will be seen from Table XIV. following, which brings into comparison all his various experiments with different proportions of sand.

The Obernai lime is yellow when not fully calcined; when a little more burned it is of a dirty yellow; afterwards it passes to ash grey; and at last, when too much burned, it is of a slate blue, and pieces of vitrified lime are often found; very similar results are produced on the Bouxvillier lime by different degrees of burning.

TABLE XIV.

Extracted from Tables II., III., XXXIV., and XXXVI., of General Treussart's Essay on Mortars, to illustrate the effect of sand upon their resistance to tranverse strain. The prisms were 2 inches square in section and 3 inches between the points of support, and were broken, as explained in the observations preceding Table IV. above.

No.	Description of Lime employed.	Resistance in lbs. of Mortars—the Lime measured in slaked powder.					REMARKS.
		1 Lime. 0 Sand.	1 Lime. 1½ Sand.	1 Lime. 2 Sand.	1 Lime. 2½ Sand.	1 Lime. 3 Sand.	
1	Altkirch	268	...	174	...	...	
2	1st Villé	119	...	68	...	...	
3	2nd do.	110	...	114	...	...	
4	Rosheim	484	...	209	...	...	
5	Hochfield	207	...	136	...	...	
6	Verdt	484	...	279	...	...	
	Mean of 1—6 . . .	278·7	...	163·3	...	...	
7	Metz	169	312	262	176	143	
8	Obernai Yellow	372	224	253	176	92	The Lime used for the prisms without sand, a different sample from that used for the other mortars.
9	,, Grey	354	400	422	187	106	
10	,, Blue	275	136	154	117	79	
	Mean of 7—10 . . .	292·5	268	272·7	164	105	
11	Obernai Yellow (2nd sample)	323	...	196	161	99	Made with the view to determine the best proportion of sand.

No.	Description of Lime employed.	Resistance in lbs. of Mortars—the Lime measured in slaked paste.						Remarks.
		1 Lime. 0 Sand.	1 Lime. 2 Sand.	1 Lime. 2¼ Sand.	1 Lime. 2½ Sand.	1 Lime. 2¾ Sand.	1 Lime. 3 Sand.	
12	Bouxvillier Grey	99	77	...	...	...	...	
13	„ Blue	79	66	...	...	...	...	
	Mean of 12—13 . .	89	71·5	...	...	...	...	
14	Obernai Yellow		301	...	275	...	242	
15	„ Brown	264	220	...	352	...	...	
16	„ „	...	297	...	165	...	...	A second sample.
	Mean of 14—16 . .	...	272·7	...	264	...	...	
17	Bouxvillier Yellow . . .	299	286	187	168	132	99	
18	Obernai Yellow	...	220	165	143	88	66	A second sample.
19	Bouxvillier Yellow	...	231	242	253	231	187	A second sample.
	Mean of 17—19 . .	...	245·7	198	187	150·3	117·3	
20	Strasburg	...	68	57	44	10	0	A pure lime.

Observations on Table XIV.

These results scarcely need comment. When the means of two or more experiments are taken, there is a loss of strength with each addition of sand, excepting in one single instance, and then the difference in favour of the larger proportion of sand is quite insignificant. According to experiments made by Colonel Nelson, in Bermuda, 1 part of lime powder barely filled up the interstices of 3 parts of sand. Now with 2½ parts sand, on the means of Nos. 7, 8, 9, and 10, there is the loss of nearly one half the strength of which the limes were capable when used without sand, and, when 3 parts of sand were used, of nearly two-thirds, the lime being measured always in paste. Again on the means of the three results given in Nos. 17, 18, and 19, an increase of sand from 2 parts to 3 parts occasioned a loss of considerably more than one half of the resistance which the prisms had when used with the lesser quantity.

Bearing in mind that these experiments were made by one who entertained, to the last, the notion that sand had generally a beneficial action on the strength of mortars, we can hardly resist the conviction that the building world must be mistaken in its theories on this question.

The next table, compiled from the result of experiments carried on by General Totten,* with the particular object of determining the proper proportion of sand to be used with lime, will throw further light on this question. The experiments were made at Fort Adams, in the United States, with Smithfield lime, which is said to be of a very fat nature. The lime was carefully ground in a mill, and the mortars, compounded with various proportions of sand, were moulded into prisms 6 inches long and 2 inches square in section. They were then subjected to a pressure of 600lbs. for a few minutes, and after 50 days from their formation, commencing in the early part of May, they were broken as in General Treussart's experiments, by a force acting midway between the points of support, which were 4 inches apart. Three trials were made on each description of prisms, and the highest results in each case taken to indicate the resistance of the mortar under trial. Colonel Totten desired, also, to ascertain the best quality of sand, and the comparative advantages of salt and fresh water in mixing the mortar. Here, as it is desired to consider only the effect of the quantity of sand used, and in practice there must always be great variety in the materials available for compounding mortar, the means of the results only with each porportion of sand are given, without distinguishing its quality, or whether salt or fresh water was used. It is well to state, however, that in all cases, whatever the quality of the sand or the nature of the water employed, the strength of the mortar decreased as the quantity of sand was larger.

* Colonel Totten on Mortars. p. 253.

TABLE XV.

Showing the weights, in lbs., required to fracture prisms moulded from mortar composed of lime and quartz sand, in various proportions, after 50 days from the time of their being formed.

Nature of Lime.	Composition of Mortar.—The Lime Measured in Paste.						
	0 Sand. 1 Lime.	¼ Sand. 1 Lime.	½ Sand. 1 Lime.	1 Sand. 1 Lime.	2 Sand. 1 Lime.	3 Sand. 1 Lime.	4 Sand. 1 Lime.
Smithfield Fat Lime......	262·5	245·6	222·5	214·7	170·3	154·6	135·1

Observations on Table XV.

It has been already observed that Sir C. Pasley made his experiments after too short a period to ascertain the effect which sand has upon mortars when more fully set. There is much to favour small samples of mortar containing a considerable proportion of sand, when they are allowed to dry quickly, as was the case in these trials. The sand not only enables the mortar to dry more quickly, and thus to impart a certain degree of strength, but it prevents the weakness which arises from the unequal shrinkage to which the pastes of lime are liable, from the evaporation of the watery parts when this proceeds rapidly. Dr. Higgins, therefore, rightly recommends the use of a large quantity of sand for stucco work. If the paste of lime merely fills the interstices of the sand, no contractions can occur, and all fissures and cracks are prevented; and we can thus understand why Sir C. Pasley's prisms gave better results, in most instances, when they contained a large proportion of sand, and why the benefit, arising from the sand, was less noticeable in joints of brickwork. The prisms were 2 inches square in section, and probably exposed to the air on three sides; the joints in the brickwork comparatively thin, and protected from the direct contact of the air. From the former he obtained the resistance; from the latter, what he considers to be the adhesiveness of the mortars; and he writes with reference to these points in his observations on the tables from which Tables XII and XIII, given above, are compiled.—"Sand appears to diminish the adhesiveness of chalk lime, but slightly to increase that of Halling lime, in either case the difference being insignificant. Its effect upon their resistances is more marked, especially upon that of chalk lime which it nearly doubles, whilst it only increases that of Halling lime by about one-half." The difference between the chalk and Halling lime admits of an easy explanation. The pure limes slake to a bulkier powder than hydraulic limes, and contract more as the water dries out. Sir Charles Pasley's experiments, in fact, show a trial of rapidity and inequality of drying, rather than one of setting properties.

To these objections the experiments of Generals Totten and Treussart are not open. General Treussart's specimens were immersed in water after 12 hours, or, as in the case of the Strasburg pure lime, kept in a damp underground cellar, and thus cracks from shrinkage and the effects of rapid drying, were obviated. And General Totten, as already stated, subjected his prisms, when they were formed, to a pressure of 600 lbs., for some minutes; and this sufficed, probably, to squeeze out of them much superfluous moisture, and to compress the mortar so considerably, as to leave little room for contraction.

We ought not to omit, however, the experiments tried by Colonel Nelson on pure lime mortars at Bermuda. They were made on joints of brickwork, which were allowed 4 months to indurate, a period insufficient for the hardening of more than a surface film of such mortars, though longer than that given by General Totten in the experiments above given. He found that 3 parts of sand to 1 of slaked lime in *powder* appeared to give the strongest proportions, and he says that this agreed with the common opinion, but 1 part of slaked fat lime in powder will only yield one-half part of paste of lime as he himself states, and thus we arrive at 6 parts of sand to 1 of lime paste, as the proper proportion, which is far in excess of the quantity recommended by any of the preceding authors. He carried his experiments so far as 12 of sand to 1 of lime paste because of the assertion of a great authority, that, "if the particles of sand were only made to adhere by a mere paste of lime, it would be sufficiently strong." He found that 1 of lime paste scarcely filled up the interstices of 6 parts of sand.*

The differences he obtained with 1, 2, and 3 parts of sand to 1 of lime powder, were small; and the experiments made were not sufficiently numerous to get rid of accidental sources of error. He commenced his experiments, too, with nearly double the quantity of sand recommended by the earlier writers, and he found the greatest strength to agree with a porportion of sand, coincident indeed with that assigned by the theory of filling the voids, but quite double that which was assigned by Vitruvius, four times that preferred by Belidor and Rondelet, ⅓ more than Dr. Higgins thought necessary to prevent shrinkage in drying, double the quantity Pasley thought best, and equal to that which in Treussart's experiments occasioned a loss of ⅔ of the strength shown by the paste of lime alone. At the commencement of this paper, reference was made to the slight extent to which Vicat found pure lime mortar to be indurated after 12 months. The carbonic acid gas had not penetrated anywhere to a depth of ⅖ of an inch, and consequently it seems impossible that in Colonel Nelson's experiments the induration of the mortar throughout the joint could have been complete. The results he obtained cannot, therefore, have much weight given to them; and, indeed, he considered himself that they were insufficient for the deduction of any general law.

The effect which time has in bringing out the weakness caused by a large proportion of sand in mortar, is decisively shewn by the results given in the following table, compiled from General Totten's work. The experiments were not made with this particular object in view, and are therefore, perhaps, the more satisfactory. The limes experimented on were the Smithfield, Thomas' Town, and Fort Adams' limes. The two first are fat limes; the last is said to be hydraulic, but showed no superiority to the others under the conditions of trial, and therefore no distinction is made between the nature of the limes, nor in the mode of slaking adopted, in order to give the mean of a greater number of results at one view. It should be mentioned, however, that whether fat or hydraulic lime was used, whether the sprinkling or the drowning mode of slaking, all the experiments tended the same way. In these trials the strength was determined by tearing asunder mortar joints uniting bricks, placed across one another at right angles on their largest surfaces, the sectional area experimented on being consequently about 18 square inches.

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* Professional Papers, Quarto Series, Vol. IV.

TABLE XVI.

Showing the mean tenacity, in lbs. per square inch, of mortars compounded with different proportions of sand, and of different ages.

Age of Mortar when Fractured.	Composition of Mortar; the lime measured in slaked paste.				Remarks.
	1 Lime. 1 Sand.	1 Lime. 2 Sand	1 Lime. 3 Sand.	1 Lime. 4 Sand.	
6 Months	23·4	21·1	20·1	16·2	Mean results in each case.
4½ Years	40·4	31·9	29·8	22·6	

Observations on Table XVI.

These results strongly support the opinion that, with the age of ordinary mortars, the proportional loss of strength occasioned by sand largely increases. Judging from the relative resistances shown by the prisms experimented on after 50 days, as given in Table XV, it might have been considered a matter of indifference practically whether 1 or 2 parts sand were employed, and the same conclusions might be drawn from the results shown in the above table for the period of six months; but when we look at the resistances after the four and a-half years the difference becomes very great, even if 31·9lbs. be allowed to be an accidentally low result for 2 parts sand. The same fact is noticeable in Nos. 13 and 14, Table XVIII following, and in Nos. 18-23, and Nos. 24 and 27, of the same table.

The next table is introduced to elucidate the question of adhesion and cohesion in mortars, and is also valuable as showing the strength of joints of quick setting cement laid between different surfaces. It is compiled from General Pasley's work on limes and cements.*

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* Pasley on Cements, pp. 128 and 129.

TABLE XVII.

Showing the comparative strength of joints of cements uniting ordinary bricks and blocks of stone, of the shape and size of bricks, after the joints had been made 11 to 13 days.

Brick or Stone.	No. of Trials.	Average comparative fracturing weights.	Comparative uncertainty of joints.	REMARKS.
Bricks	12	1·	·14	Taking the first five experiments only to determine uncertainty of joint.
Kentish Rag . .	5	·99	·10	One unusually low result, resulting from a very fluid joint, omitted. Col. Pasley noted the bad joint at the time of formation.
Bath Stone . .	5	·81	·13	
Cornish Granite, polished. . .	2	·68	. . .	Comparative uncertainty omitted, as there were only two experiments.
Cornish Granite, rough. . . .	5	·66	·27	
Portland Stone .	5	·63	·01	
Craigleith Sand Stone. . . .	5	·63	·30	
Yorkshire Landy	5	·60	·40	

Observations on Table XVII.

General Pasley did not consider these experiments to be absolutely conclusive, because the number of them was small. He thinks, however, it may safely be inferred from them "that the adhesiveness of cement to the least congenial sort of stone is more than ½, and from thence to ⅔ of its adhesiveness to bricks;" now the least congenial sorts of stone, as he terms them, are those which in great measure chemically resemble the components of ordinary granite sand, the Portland stone being the only exception, and since the cohesion of the cement particles must have been equal, at least, to the force required to separate the bricks united with them, it must manifestly have been about ½ greater than the force of its adhesion to the quartzose and granitic surfaces. The weakening of cement mortar by the addition of ordinary quartzose sand, may in part be accounted for them, on the principle of the lesser force of its *adhesion* being substituted, in part, for that of its *cohesion*, and the results in the table strengthen, if they do not confirm, the attempt made above to explain the injury done by sand to lime mortars on these grounds. Sir Charles Pasley calls the table from which the above is compiled, a table of the comparative adhesiveness[*] of cement to *bricks*, and to various sorts of stone; but this it manifestly is not, unless the cohesion of the cement particles was, in the highest result (viz., with the brick), superior, or exactly equal to its adhesion to the brick surface; of this he gives no proof, and experiments recently tried at Chatham tended to show the contrary. The great adhesion in the case of the Kentish rag stone, as compared with the Portland stone, is curious, since chemically they are of the same nature, and from the greater roughness of the latter, one would have expected a contrary result. It is just possible it might have arisen from the assistance which the crystalline nature of the Kentish rag stone gave for the deposition on it of crystals of carbonate of lime from the mortar where the joint came in contact with the air. It is well worth remark, as affecting the question of the effect of sand on mortar, that the quartzose surfaces gave the most uncertain joint as well as the weakest.

It would seem, therefore, that, with the exception of sand of brick, or other similar substances such as arènes, the calcareous sands should give the best results with mortars.

The following table contains chiefly the results obtained recently at Chatham, with different proportions of sand, both on limes and cements. The experiments were made by men impressed with the truth of the common notion, and their results first led the writer of this paper to investigate the question.

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[*] Sir Charles Pasley appears throughout to take it for granted that the force required to separate bricks united with mortar, is a measure of the adhesion of the mortar. It would of course only be so in the cases in which the mortar separated clearly from one of the bricks; in other cases it is a measure of the tenacity, or cohesion, of the mortar alone, or partly of its cohesion and partly of its adhesion.—H. S.

TABLE XVIII.

Showing the effect of sand upon mortars of lime and cement, as determined, by recent experiments at Chatham and Holyhead, and by experiments made some years since at Bermuda by Colonel Nelson. In No. 1-6 the trials were made by blows with a hammer, and scratching with sharp tools, and the numbers indicate comparative resistances only. In No. 7-23 the resistances are given in lbs. per square inch, the trials having been made by tearing joints asunder. In No. 24-27 the resistances were obtained by subjecting prisms of mortar 3 inches between the point of support, and 2 inches square in section, to a transverse strain applied at their centres. In No. 28-29 the resistances were obtained by crushing cubes of mortar of 1 inch side. From Nos. 7 to 29 the results given indicate the breaking weight in lbs. for the descriptions of mortar specified.

No. of Set.	Nature of Lime or Cement.	No. of Trials.	Age of Mortar in Days.	Composition of mortar; the lime estimated in powder previous to slaking.									Remarks.
				For 1 part of Lime or Cement powder.									
				0 Sand	1 Sand	2 Sand	2½ Sand	3 Sand	4 Sand	5 Sand	6 Sand	7 Sand	
1	Lias lime . . .	...	1460	...	4·5	4·0	...	3·5	2·0	1·5	...	...	Estimated by Capt. Schaw.
2	Roman cement .	...	1460	...	6·5	4·5	...	2·5	1·5	1·0	...	...	
3	Medina cement .	...	1460	...	9·0	7·0	...	4·5	4·0	3·0	...	...	
4	Scott's cement, prepared from ordinary Halling lime	...	1460	...	10·0	7·5	...	7·0	6·5	5·0	...	...	
5	White's Portland cement	...	1460	...	10·0	8·5	...	8·0	7·5	7·0	...	...	
6	Scott's cement, prepared from Lias lime	...	90	...	10·0	7·7	...	6·2	...	...	...	...	Mean of estimates by Lieut. Colonel Gallwey, and two other officers of Engineers
7	Bermuda coral lime	6	122	...	...	...	...	...	...	2·6	3·25	2·5	Colonel Nelson.

8	Roman cement .	5 to 15	11	40·0	27·9	17·8	...	15·4	14·9	7·3	...	...	Extracted from Corps Papers, Vol. 10, 2nd Series. Observers: Captain Schaw, Lieutenant Moncrieff, and Captain Scott; the joints made by Corporal Grey, R.E.
9	Medina do. .	5 to 15	11	40·0	35·2	27·1	...	20·1	14·9	8·3	7·5	...	
10	Atkinson's do. .	5 to 15	11	...	38·5	17·5	...	7·9	4·9	...	...	...	
11	Bath do. .	5 to 15	11	...	26·1	13·5	...	12·8	...	...	...	...	
12	White's Portland cement	5 to 15	11	bricks generally broke.	50·4	43·3	...	30·3	42·0	23·8	26·5	...	
13	Scott's cement, from ordinary Halling lime . .	5 to 15	11	29·2	28·6	30·8	...	32·8	28·1	19·4	18·4	...	
14	Scott's cement, from ordinary Halling lime . .	5	30	52·1	51·4	52·7	..	52·8	33·1	39·8	31·7	...	
15	White's Portland .	5	30	bricks generally broke first.		66·7	...	50·5	52·1	35·6	36·5	...	
16	Roman cement. .	5	30	49·9	42·4	23·6	...	...	...	...	...	..	
17	Medina cement. .	5	30	51·2	63·8	37·0	...	...	...	...	...	...	
18	Lias lime . . .	2	61	...	...	...	8·85	9·38	...	...	...	...	Nos. 18, 19, and 20 were exposed to the air. Nos. 21, 22, 23, immersed in water. Aggregate resistance with 2½ sand 43·14; with 3 sand 41·82. Observer: Mr. Thomas Harris, Resident Engineer at Holyhead.
19	Ditto. . . .	2	122	...	...	...	5·6	9·38	...	...	...	...	
20	Ditto. . . .	2	365	...	...	...	13·6	11·53	...	...	...	...	
21	Ditto. . . .	2	61	...	...	...	5·63	7·57	...	...	...	...	
22	Ditto. . . .	2	122	...	...	...	6·56	5·28	...	...	...	...	
23	Ditto. . . .	2	365	...	...	...	1·61	nil	...	...	...	...	
24	Scott's cement . .	5	30	...	382	333	...	263	242	172	...	...	Captain Schaw, Lieutenant Moncrieff, and Captain Scott; the prisms moulded by Corporal Grey.
25	White's Portland cement	5	30	...	529	538	...	322	158	151	...	...	
26	Roman cement .	5	395	...	562	214	...	102	...	...	...	...	
27	Scott's cement, from ordinary Halling lime . .	5	395	...	780	650	...	410	...	...	...	...	
28	Scott's cement, from Lias lime .	2	270	1913	...	...	...	...	...	...	...	...	Sergeant Hartley.
29	Ditto. .	1	270	...	...	...	..	300	...	...	...	...	

Before leaving this subject it may be advisable briefly to recapitulate the contradictory evidence of writers and experimenters who hold to the beneficial effect of sand on mortars, and to contrast this with the simplicity of the view here advocated. Pasley thought, with Belidor and Rondelet, that hydraulic limes would carry with advantage less sand than the fat limes, because they worked short with a smaller proportion of it. Vicat decided by experiment that they would carry more. Writers, generally, have asserted that the fat limes are benefitted by a considerable quantity of quartz sand. Vicat and Raucourt de Charleville assert that they are injured by a small proportion of it, and consider they have proved the point by experiment. Raucourt explains why it is that "cements," in which term, as already explained, he includes all argillaceous limes, are peculiarly benefitted by making mortar of such proportions as will enable the "cement" to fill up the voids of the sand. General Pasley asserts that cement is injured by any proportion of it. At the same time, on examining the results of the only experiments which have been given in a satisfactory form and are free from objections, we find the views advocated in this paper fully borne out, for not only do they show that the theoretic rule of just filling the voids of sand is founded in error, but that, as regards strength in heavy structures, where cracks from shrinkage or drying are not to be apprehended, all limes are weakened by even small proportions of it. The limes tried by Treussart after one year, without sand, and with the theoretic quantity, lost $\frac{2}{3}$ of their strength in the latter case. The trials of Colonel Totten after $4\frac{1}{2}$ years, with $\frac{1}{6}$ and $\frac{4}{6}$ of the theoretic proportion, showed a resistance in the case of the larger proportion little greater than $\frac{1}{2}$ of that which it showed with the less. The tendency of both their experiments points unmistakeably to a loss of strength by each addition of sand in the case of limes, and Table XVIII shows the same rule to hold good with cements. From the one view all is confusion and uncertainty, from the other, the view here taken, there are no unaccountable anomalies to be reconciled, and there is a gradual decrease of strength with each addition of sand throughout the whole range of calcareous mortars—in the fat limes, as asserted by Vicat and Raucourt de Charleville, and as shown by the results obtained by Colonel Totten—in the cements, as established by Pasley—and in the intermediate sorts of hydraulic limes, as satisfactorily decided by the careful experiments of General Treussart. There were necessarily some instances in which a trial, or set of a few trials, gave a result so much below the average, as to place it lower in the scale of resistance than a mortar containing more sand; but, with the same proportion of sand, a lime is often found to give resistances differing so widely as to show that these discrepancies are accidental, and arise from imperfections in compounding and applying the mortars, or in preserving the specimens.

Enough has now been brought forward to show how unsatisfactory and contradictory are the statements made and the rules followed, by the theorizers on the effect of sand on mortars used in brick and stone masonry, and it is hoped a consideration of all the evidence will lead to the conviction that this is not a question to leave to be resolved by the convenience of the workman and the interests of the builder. Exception is taken, not so much to the proportion of sand *specified* for works, (for this is generally moderate, and would cheapen the mortar without materially detracting from the resistance of the masonry) as to the practice which permits a departure from the specification, and any quantity to be introduced that does not render the mortar "short," on the supposition that the plasticity which best satisfies the skilful workman is the surest criterion by which to judge of the proportion of sand and lime to secure the greatest resistance, and on a fanciful theory derived from the composition and hardness of granite.

5.—On Sand as an Ingredient for making Mortar.

We shall now give at some length the opinions of writers and builders on the effects of sand as obtained from different sources, and make an attempt to extract what is valuable from the conflicting evidence on this head.

Vitruvius prefers pit sands, but says that they must be freshly dug; otherwise they are decomposed by the action of the atmosphere and become earthy, and in this state they make bad mortars.* Alberti, Palladio, Philibert Delorme, Blondel, and some other writers agree in these opinions, but Belidor thinks that river sand is best, and that it should be sharp. Palladio considers that white sands are worst. Belidor states that colour has nothing to do with the matter. Rondelet, in consequence of these contradictory opinions, made experiments himself on the subject, with the following results :—

1st. That the glassy or quartzose sands form with lime a weaker mortar than mixed sands, and that such mortar is longer drying. 2nd. That pit sand produces a better mortar than that made with river sand composed of grains of the same size. He did not find that the sharpest *("plus arides")* sands made the best mortar, but thought that of sands of the same kind those which were deepest in colour, excepting the yellow, were to be preferred. The best sands, he states, are such as hold a middle place between those which are very plastic and very sharp.

On comparing mortars made with freshly dug pit sand, and the same sand washed and dried in the sun, the sharp *(arides)* grains only being left, he found that the first acquired the greatest hardness, and that mortar made with very fine sand did not harden so well as that made with sand of a moderate sized grain.†

All these authors considered sea sand the worst, but Alberti mentions an exception. The sea sand from the neighbourhood of Salerno he found to be as good as the best pit sand.

Treussart appears to think there is not much difference between river, sea, and pit sand; and he believes that the discordant results obtained by preceding writers were occasioned by their having employed sands more or less fine, or more or less earthy. If they did not wash their sand the superiority which they found to belong to either, may have been, he thinks, on the one hand, due to the greater freedom from earthy matters of the better sand of the two, and on the other, to the greater fineness of the particles. His experiments indicated fine sand to be preferable to coarse, but he states that many constructors think coarse sand to be preferable for heavy masonry, and he believes that the prism, made with coarse sand in the experiments from which he draws his conclusions, was cracked without his perceiving it, its resistance having been so feeble.

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* "Vitruvius." Book 4. Chap. II.

† "Rondelet. L'Art de bâtir." Livre II. Art. 2.

He considers, however, that it is certain that there is an advantage in the case of hydraulic limes in making mortar of fine sand. When he employed pit sands he always washed them, but points out that it is necessary before doing so to ascertain that the sands are not arènes. He finally decides that fine sand affords much better results than coarse, both in *air* mortars and water mortars, notwithstanding the opinion to the contrary of most constructors.*

His remark concerning the washing of arènes suggests the possibility that Rondelet made his experiments on this sort of sand, and thus obtained the otherwise anomalous result of a deterioration in the sand by washing.

Vicat concluded that the advantage of the three different descriptions of sand employed by him varied with the nature of the lime. He calls coarse sand that whose grains, supposing them round, vary from one-seventeenth to one-eighth of an inch in diameter; fine sand, that where the grains vary from one-twenty-fifth to one-seventeenth of an inch in diameter; powders, such solid substances as have no particles equal to one-hundred-and-twenty-seventh of an inch. in diameter.

These sands, according to his statement, hold the following order of superiority with the limes mentioned,—

	1st.	2nd.	3rd.
For eminently hydraulic limes..........	..Fine	Mixed	Coarse.
For slightly do. do.	Mixed	Fine	Coarse.
For rich limes..........................	Coarse	Mixed	Fine.

Powders, especially when derived from calcareous substances, he found to make excellent mortar both with hydraulic and eminently hydraulic mortars.

He thinks that the greatest difference in the hardness of mortars of the rich limes which the use of this or that sand occasions, rarely amounts to one-fourth of the hardest, but that with hydraulic and eminently hydraulic limes, it may exceed one-third.†

Colonel Raucourt de Charleville considers that sand from the banks of rivers is better adapted for mortar than that which is procured from the middle of their beds; in the latter position the particles are rubbed smooth, but on exposure to the air, the surfaces of the grains become pitted, and adhere better to the lime. He found that mixed sand, that is a mixture of coarse and fine grains, was most economical.‡

Of our own countrymen; Mr. Worledge observes that fine sand makes weak mortar, and that the larger the sand the stronger is the mortar.§ Dr. Higgins prescribes a mixture of fine and coarse sand. ||

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* "Treussart, Mémoire sur les mortiers." Sect. 2., Chap. 12., and Summary to Sect. 1.

† "Vicat. On Limes and Cements." Chap. XI. Par. 210, 214.

‡ "Colonel Raucourt de Charleville, L'art de faire de bons mortiers." Chap. II.

§ "Nicholson's Dictionary." Art., Mortars.

|| "Higgins on Calcareous Cements." Sec. XII.

Smeaton remarks "That Vitruvius was not only a judicious but a *practical* observer, as well in regard to *mortar* as other articles of building, appears from the distinction he makes between *Sharp River* sand and *Pit* sand, which is generally soft; for of river sand he allows but two "(of lime)" to one of sand. I have long since found the necessity of forming a composition of fine and coarse sand for mortar, unless the sand is naturally so mixed, for, as the lime will receive most sand in that way without losing its plasticity, it will of consequence make the hardest and firmest mortar. My practice has uniformly been, if there was plenty of one sort of sand, and a scarcity of the other, to make the mixture, by allowing of the most plentiful sort as far as the proportion of 2 to 1."[*]

Peter Nicholson states that the coarser the sand the stronger is the mortar.[†]

General Sir Charles Pasley had not, apparently, his attention called to the influence of particular kinds of sand.

Colonel Totten made careful experiments on the influence of the size of the grains of sand on fat lime.

The sand named No. 1 in the table below had no grains below one-twelfth of an inch in diameter, and they varied between this and one-sixth of an inch.

No. 2 had grains varying from one-twelfth to one-forty-eighth of an inch.

No. 3 had no particles more than one-forty-eighth of an inch in diameter.

No. 4 was No. 2 pounded very fine after being freed from dust by washing.

TABLE XIX.

Showing the influence of the size of the grains of sand on prisms of mortar 6 inches long, 2 inches square in section, fractured after 50 days; the distance between the supports being 4 inches, and the power acting midway between them. The maximum result of each set of 3 experiments is given as in the original table.

Composition of the Mortars.	Sand and Fresh Water.				Sand and Salt Water.	
	No. 1.	No. 2.	No. 3.	No. 4.	No. 1.	No. 3.
Lime in stiff paste 1, Sand ¼ . .	224	220½	248½	253½	192½	234½
Do. do. 1 do. ½ . .	213½	234½	234½	241½	210	199½
Do. do. 1 do. 1 . .	248½	220½	227½	234½	178½	178½
Do. do. 1 do. 2 . .	164½	199½	161	178½	140	178½
Do. do. 1 do. 3 . .	157½	189	185½	157½	119	119
Do. do. 1 do. 4 . .	126	227½	157½	136½	101½	154
Means	189	215	202	217	157	176

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[*] "Smeaton's Narrative." Note. p. 120.

[†] "Nicholson's Mechanical Exercises."—Bricklaying. Art. 32.

Observations on Table XIX.

Colonel Totten remarks on these results "that it appears that coarse sand, or rather, sand composed of coarse and fine particles (sands Nos. 1 and 2,) is a little inferior to sand that is all fine, (sands Nos. 3 and 4;) in thirty-six comparisons, six exceptions; and also that sand reduced by pounding to a fine powder afforded some of the best results of the Table."*

So far as an extreme case may be depended upon, and the results from experiments on cements may be considered to apply to limes, our Chatham experiments have tended to show that coarse sand is best. Where four parts of small pebbles of the size of horse beans and peas were employed in the one case, and three parts sharp mixed sand in the other, prisms of mortar of Scott's cement, two inches square in section, and three inches between the points of support, and weighted at their centres, were fractured respectively with 942 lbs. and 410 lbs., after twelve and a half months.† It seems possible that in Colonel Totten's experiment, as he used a rich lime, the shrinkage may have been unequal with the very coarse sand (No. 1), and an element of weakness have been thus introduced. None of the differences of the means are important.

Smeaton's opinion was evidently formed on economical grounds, and his theory that sand renders a mortar harder, by introducing into it a harder body than the lime. This theory has been already discussed.

On considering all the evidence brought forward, and its very contradictory nature, it may be considered that our present knowledge and experience would not justify expense, in order to obtain for brickwork or masonry, quartz sand of any particular colour, size of grain, or from any particular source, though it may be assumed that such as is rough and sharp will be preferable to smooth grained sands. M. Girard de Caudenberg states, in his "Notice sur les Mortiers hydrauliques," that he had ascertained by experiment that sand of broken flints gave to prisms of mortar greater resistance to a strain, applied in the direction of their length, than round smooth sand, in the proportion of 5 to 3. For fine joints, a very coarse sand is evidently unsuitable. Little weight can be given to the opinion of the older writers on the unfitness of sea sand for *hydraulic* mortar for masonry, whether this opinion is founded on the nature of the sand, or the presence of saline matter. Alberti pointed out one exception; Davy says, "it is almost unnecessary to observe that washed sea sand will produce precisely the same effects as the best river sand;" and M. Millet de Monville in the composition of a mortar for hydraulic works specifies that sea water shall be used in its preparation.‡ Smeaton also concluded from his own experiments that there was no need "to burthen himself with carrying out fresh water to the Eddystone for making the mortar, those specimens made up with salt water appearing after three months, if there was any difference, to have the preference."§

Peter Nicholson, it is true, says that "if sea sand is used it requires to be well washed with fresh water, to dissolve the salt with which it is mixed, otherwise the cement into which it enters never becomes thoroughly hard and dry."*

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* "Totten on Mortars." Chap. 25.

† See remarks on the action of sand at page 23. The greater strength of the concrete prisms may have been due to the length of the course which the fracture took, owing to the interlacing of the gravel and sand, which counteracted the weakness produced by the siliceous matter more than when this consisted of sand only. If this be the case, it would be an argument for using sand of mixed sizes.

‡ Belidor. Arch Hydr. Part 2. Tom 2.

§ Smeaton's Narrative. Book 3, Chap. IV., Par. 171.

Partington also in his Builders' Complete Guide, states that "the fittest water for making mortar is rain water, river water holds the next place, land water the next, spring water the last; sea water and all waters noticed medicinally or otherwise, for their saline contents, ought never to be used for this purpose."†

And Colonel Totten decided from the experiments given in Table XIX. preceding, that mortar made with salt water "was decidedly weaker than those made with fresh water; one exception in twelve comparisons." Since, however, his experiments were made with rich lime, and this, as has been already shown, acquires its first resistance more by drying than setting, it seems probable that the sea water may have here caused weakness by keeping the prisms damp; and as good hydraulic limes were little known in London in the time of Nicholson and Partington, they also probably judged from what they noticed with pure or very fully hydraulic limes, and that more especially in plastering.

Lieutenant-Colonel Lovell experimenting with a moderately hydraulic lime at Portsmouth, concluded that the specimens of mortar made with salt water had a decided advantage over those made with fresh.

On reviewing these opinions concerning the action of salt, and bearing in mind that some of the builders named were dealing with limes which set best when kept damp, and that others may have been dealing with fat limes, with which damp would occasion a retardation of the set; it seems reasonable to conclude that the observers were not mistaken in either instance, but that for hydraulic limes, either sea sand or sea water may be used in brickwork and masonry, generally, without injury, if not with advantage. For plastering internally it is universally agreed that sea sand should be either rejected or washed, as the presence of salt will always keep the plastering damp and unfit to receive either paper or painting—of course to use sea water would be still more objectionable. For the internal parts of magazines and stores, also, sea water, and perhaps unwashed sea sand, may retard the drying and attract moisture sufficiently to render their use unadvisable. Some of the nice distinctions, however, drawn between waters from different sources by Partington and others can be of little importance in any case, and of none for heavy masonry.

In one point all writers excepting Rondelet, who may have been dealing with an arène, are agreed. They all have decided that the sand must be clean.

Vitruvius says it must not be mixed with earth.‡

Smeaton ascertained by experiment that a small proportion of clay greatly interfered with the induration of mortar. Peter Nicholson, who quotes him, complains of the use by London builders of loamy sand, and compares this practice with that of the Romans, who were most particular to employ only clean sands.§

Vicat says, "it cannot be too often repeated, that the intervention of any loamy or argillaceous particles in the above mentioned powders robs them of

* "Nicholson's Mechanical Exercises."—Bricklaying. Art. 32.

† "Partington. Art., Bricklaying."

‡ "Vitruvius." Chap. IV. Book 2.

§ "Smeaton's Narrative." Book 3. Chap. IV.

their qualities."* "Loamy or argillaceous particles deprive powders of sands, which are largely impregnated with them, of the faculty of composing mortars capable of enduring exposure to the weather, in conjunction with the powerfully hydraulic limes and, *à fortiori*, with the rich limes."† Colonel Raucourt de Charleville adopts the same view. Sir C. Pasley states that "the sand should be clean, that is free from all earthy matter, or other than silicious particles. Hence road scrapings always, as being a mixture of sand and mud, and pit sand generally, as being scarcely ever without a proportion of clay, should be washed before they are used," "None but *clean* sharp sand will ever form good mortar."‡

Treussart experimented on an earthy sand obtained from a pit near Phalsburg —that portion of it which was washed gave better results than clean river sand; when not washed, the experimental prisms made with it could not support the weight of the scale. The mortars were made of two kinds of moderately hydraulic lime.§ After these experiments he used in this locality no sand but washed Phalsburg pit sand, though it required 70·68 c. f. of the earthy sand to yield 35·34 c. f. of the washed sand, and 0·62 of a day's work for the washing of this quantity; with this preparation, however, it cost less than bringing the river sand.

Peter Nicholson complains that "to complete the hasty hash which was called mortar in his time, screened rubbish and the scrapings of roads, also, are used as the substitutes for pure sands;"‖ and it may be truly asserted that at Chatham, at least, clean sand is the exception and not the rule both in Government and Civil Buildings. For the Admiralty works, however, clean sand is procured.

Here we find no disagreement sufficient to leave any doubts as to the validity of the common opinion against the common practice. It is stated that one-seventh or one-eighth of clay in the sand used in making mortar causes the mortar to moulder in winter like marl, for clay absorbs water to a much larger extent than lime and sand. There seems, then, the best ground for great stringency on that item of all specifications which prescribes that the sand shall be clean as well as sharp, but which, at present, is a dead letter. Few of us have ever seen a vat for washing sand, or indeed any sand washed at all, excepting for the finishing coat in plastering, and even in this case it is often dispensed with.

6.—ON THE SLAKING OF LIME.

The next point to be considered is the mode in which the lime should be slaked. Many opinions have been expressed on this subject also, but fortunately, the most generally approved is also one of the simplest of execution.

The methods employed have been generally divided into three—ordinary extinction, immersion, and spontaneous or air slaking. The first, which is most commonly used on the continent and often in this country, consists in throwing on the lime, as it comes from the kiln, enough water to reduce it to a thin paste. Too much water is in this method generally added in order to facilitate the mixture with the sand. The lime is, as it is termed, drowned, and the slaking is checked.

* "Vicat. Lime and Cements." Chap. XI.

† "Ibid." Appendix LX.

‡ Pasley on Limes and Cements. Par. 9.

§ Treussart on Mortars. Sec. 2, Chap. XII.

‖ Nicholson's Mechanical Exercises. Art., Bricklaying.

The second method of French writers consists in plunging quick lime into water for a few seconds, and then throwing it into a heap and allowing it to fall to a powder. The operation is performed in baskets, the lime being broken to the size of an egg before immersion. M. de Lafaye proposed this method towards the end of the last century as a secret recovered from the Romans. There are various difficulties in this mode of slaking lime, the chief being that the workman cannot be made to hold the lime in the water the requisite time. A modification of this process is much used in this country. Enough water is thrown on the lime to slake it to a powder, and then sand is heaped over it to cover it all up and retain the warmth and moisture. The quantity of water necessary to bring the ingredients to a paste is added subsequently.

The third process is that of exposing the lime to the air until the moisture throws it abroad.

Writers are not at all agreed as to the best method of effecting the operation of slaking, or on the absolute resistances obtainable according as the one or the other method is employed.

In his first memoir Vicat writes, "Such are the three modes of slaking lime; the first," (the ordinary method) "is generally used; the second," (by immersion), "has scarcely been employed except by way of trial on several works; the third," (or spontaneous method), "is proscribed and represented in all treatises on construction as depriving the lime of all energy, to such a degree that those portions which the air has thrown quite abroad to a powder, are regarded as lost. We shall see hereafter, as regards spontaneous slaking, how much one should mistrust general assertions arising from inaccurate observations, and accredited by authors who, believing everything, repeat without examination the errors of others."*

In his subsequent work on limes and cements he says, that the hardness acquired by mortars varies with the mode of slaking made use of, and that the three common processes bear the following relation of superiority to one another.

With the Rich Limes.	With the Hydraulic Limes.
1st. Ordinary Extinction.	1st. Ordinary Extinction.
2nd. Spontaneous.	2nd. By Immersion.
3rd. By Immersion.	3rd. Spontaneous.

Treussart remarks in allusion to Vicat's observations concerning air slaking, given in his earlier work—"The results I have obtained have been far from confirming what Vicat says."†

Treussart found the method of air slaking to be the worst both for fat and hydraulic limes, and he preferred sprinkling the lime as it came from the kiln, much in the method adopted for hydraulic limes in this country, to either of the other plans.

Colonel Raucourt de Charleville says, that the methods by immersion and by air slaking retard the set of hydraulic and eminently hydraulic limes, but suit the feebly hydraulic and pure limes better than the ordinary method: and he gives many minute directions to be observed under different circumstances.‡

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* Vicat, "Recherches experimentales," Chap. IV., and "Mortiers et Ciments," Chap. XI.

† "Treussart, Mémoire sur les mortiers." Section I., Chap. II.

‡ "L'Art de faire de bons mortiers," Art. 89.

General Pasley says,—"Not having myself tried the strength of what M. Vicat calls fat, hydraulic, and eminently hydraulic limes, after slaking them in various modes, I cannot say more upon his nice distinctions in respect to the slaking of limes, than to express my doubts as to the accuracy of his opinions on this head, which do not carry conviction to my mind, except so far as his objections to excess of water extend, for both in cement and in lime I have found by experiment, that what M. Vicat aptly terms drowning is prejudical to them."*

In this last opinion all writers are in accord, and since the first method is allowed to lead to this abuse, and it does not secure the perfect slaking of over burned particles of hydraulic lime, it should be proscribed for making mortar for heavy masonry. The third method would be extremely costly in a large way,—the majority of writers think badly of it,—and chemically, there are reasons against its employment, though at Lewes excellent outside stucco work is executed with lime so slaked.

The second method, as modified in our own general practice, has in its favour the authority of Treussart, who was an eminent practical experimenter as well as builder. It is certainly less open than the first, to injurious treatment and is far better adapted than it, to obviate the effects arising from the sluggish slaking of the over burned particles of hydraulic limes.

In its application to the pure limes, it little matters whether large or small quantities are slaked at one time, but with the hydraulic limes only so much should be slaked at once as can be worked off within the next eight or ten days. Flare burned and feebly hydraulic lime should be left covered for a period varying from twelve to twenty-four hours, as convenience may dictate, but it will be safer to leave the hydraulic and eminently hydraulic limes for 24 or 48 hours before making them into mortar. The quantity of water required to be thrown on the lime will vary with the density and purity of the lime and its freshness; but it may be assumed generally that the quantity necessary will lie between ⅓ and ½ the bulk of the lime. With pure and fresh burned lime, more water is evaporated by the heat produced, than with a staler or a hydraulic lime.

7.—ON MIXING THE INGREDIENTS OF MORTARS.

The sand and slaked lime have now to be mixed. This can be done either by hand or by machine. The great object to be accomplished is the perfect admixture of the sand and the lime; but according to some writers continued working and beating is essential to the making of good mortar independently of the thorough intermingling of its components.

M. Félibien observes, "that the ancient masons were so very scrupulous in this process that the Greeks kept ten men constantly employed for a long space of time to each basin; this rendered the mortar of such prodigious hardness, that Vitruvius tells us, the pieces of plaster falling off from old walls served to make tables. The same Félibien adds, it was a maxim among old masons to their labourers, that they should dilute it with the sweat of their brow, *i.e.*, labour at it a long time, instead of drowning it with water to have done the sooner.†

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* Pasley, "Limes and Cements." Appendix LXIV.

† "Nicholson's Archi: Dictionary," Vol. II., Art. Mortar.

M. Rondelet states that he had assured himself by many trials, that the more a mortar is beaten the harder it eventually becomes and the quicker it sets—but he seems to attribute this to the more intimate union and admixture of lime and sand which is thus brought about, than to any chemical change.*

M. Vicat asserts that in whatever way the lime has been slaked, it should be brought to the condition of a homogeneous paste before the sand or other ingredients are mixed with it. He gives various rules for beating mortars in moulding, but these explanations hardly apply to the point now under consideration.

Colonel Raucourt de Charleville recommends that when sands of different degrees of coarseness are to be used, the lime should first be mixed with the finest sand; that then a sand of coarser grain should be added, and so on. This mode of operating, he states, diminishes the labour, and gives the best and most homogeneous mortar. He considers that to grind, or pound ("broyer") the mortar is of the greatest value in the case of the hydraulic limes; that the inert portions of such limes have frequently the strongest setting properties, and that where grinding is not employed, these sluggish parts must be raked out and rejected. He states, however, that sand must not be added before grinding. That "it is admissible to grind the limes and the puzzuolanas ("terres") apart or together; that a small amount of force can break these down, and produce important results, but as to the sands, what necessity can there be to reduce them to ("sablons") powders? If we must have these in our mixtures, it would be better to take them in this natural condition and add them to the mortar, than produce them at a heavy expense."†

Treussart says, "Experiments which follow will show that it is an error to insist that mortar should be mixed with the "sweat of the labourer," it is enough if the sand be well mixed with the lime." Again, he says, a great deal of trituration is useless either with hydraulic or common limes. It is enough if the mortar be homogeneous, which is the case when a heap of about 35 c. f. has been passed under the rab five or six times by four men. Mortar made of ordinary consistence and even rather thin, is easier to mix thoroughly, and gives better results than when it has been mixed in a stiff state."‡

Peter Nicholson complains of the hasty manner in which in his day the London workmen compounded mortar, and attributed to beating something further than the advantage derived from a more perfect mechanical mixture; he states it to be of the utmost consequence to its durability.§

All are agreed then as to the necessity of an intimate *mixture* of the ingredients of the mortar, the only doubt being whether there is any further advantage attending it. Neglecting the advantage, aimed at by Smeaton, of introducing more sand without depriving the mortar of its plasticity, it seems probable that beating does approximate the particles of lime pastes and particularly of the bulky pastes of rich limes, and thereby impart greater density to their mortars and greater resistance, consequently, after induration. There is room for doubting, however, whether the increase in the hardness so produced would of itself, and without reference to the more perfect intermingling of the particles of lime and sand which beating must occasion, compensate for the labour of the process, unless done by machinery.

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* Rondelet. L'Art de bâtir. Livre 2. Art. 4.

† L'Art de faire de bons mortiers. Art. 73-74.

‡ "Treussart, Mémoire sur les mortiers." Sect. 1, Chap. X.

§ "Nicholson's Mechanical Exercises." Art. Bricklaying.

Colonel Raucourt de Charleville has given a good reason for grinding or pounding being beneficial with hydraulic limes, and especially with puzzuolanas and other earths of a like kind.

The remarks made above on the wretched mixing of the mortar used at Eastbourne, where particles of lime larger than peas, and in great abundance, escaped slaking before the mortar was introduced into the work, or the inspection of any hard made mortar, after setting, will show how little the sweat of the labourer has done towards moistening it, and how important it is not to trust to his care and diligence, or even to his powers of making a good mixture, whatever his will. Davy indeed prefers the ordinary or larrying method of making mortar, because the mixture of lime and sand can thereby be made more perfectly, whereas by the method of sprinkling, recommended in this paper, there are, he states, always small particles of the lime that cannot be properly mixed, however much it may be chafed up.*

We may then assume that wherever the work is of sufficient extent to justify the first outlay on machinery, hand made mortar should not be allowed. The cheapest good method of mixing is probably that, now commonly adopted on large works, of grinding the ingredients together under an edge stone. This is recommended, not with the view of reducing the sand to a powder, but of breaking down all unslaked particles, and of perfectly incorporating and condensing the ingredients. If the edge stone system is too expensive to adopt, a pug mill forms the best substitute for it. The safest plan with strong hydraulic limes is undoubtedly to grind the lime to a fine powder before mixing it with the sand.

Puzzuolana, and other like substances, absolutely require to be ground very fine as well as to be intimately mixed with the lime in order to develope their properties, as has been already remarked.

When the lime is first ground to a powder, and is then partly mixed with the sand before any water is added, as is done with cements, it is probable that much better hand mixtures could be made, but there is danger in permitting lime to be ground before it is brought on to the ground, for reasons hereafter to be explained, and it is essential that it should be finely ground, for the over-burned particles which generally escape grinding are precisely those which most require it.

8.—On Estimating the Ingredients of Mortar.

We have now to consider the best method of estimating the components of mortar. With the sand there is no difficulty. It can most conveniently and accurately, as far as mortar making is concerned, be measured by volume, and though this varies according to the degree of moisture in it, such variation is unimportant in practice. With the lime, however, there is much uncertainty unless the weight, the entireness of the calcination, and the freshness of the lime, be considered as well as volume. The size of the lumps, if the lime is delivered from the kiln, also influences the question. Taking lumps of the extreme size produced by flare burning, and comparing these with an equal volume of the same lime from a tunnel kiln, Pasley estimated that the latter would give the greater weight by 10 per cent.[*] Again if the measurement, with the same description of lime, was sufficiently certain to give always the same weight per given volume, there is an immense difference in the absolute quantity of lime in the same bulk of different sorts of lime. A bushel of grey chalk lime weighs only 50 lbs.; a bushel of Plymouth pure lime about 70 lbs.; and a bushel of Keynsham lias lime, 80lbs.

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* Davy on Artificial Foundations. Chap. VI.

It manifestly, therefore, would be an inaccurate mode of proceeding to estimate the quick lime by volume alone, without reference to weight.

If the lime is delivered ground, the time which may have elapsed since the lime left the kiln, the degree of exposure to which it has been subjected, the degree of compression given to it, and the season of the year, will greatly affect the amount of lime in a given volume. Sir Charles Pasley found that 1,000 cubic inches of powdered chalk lime, weighing 24·81 lbs., kept in a dry apartment, in a compact box, open at the top, and exposing rather more than one superficial foot to the action of the air increased—

After	3	days,	14	per cent.	in bulk,	2¾	per cent.	in weight.
„	7	„	25	„	„	5	„	„
„	10	„	35	„	„	6½	„	„
„	14	„	44	„	„	8	„	„
„	17	„	54	„	„	9½	„	„
„	42	„	101	„	„	15[†]	„	„

In lump the action of the air will not affect the volume to the same degree, the portions which fall abroad only filling in the interstices of the lumps which remain.

If it be attempted to regulate the amount of lime by measurement, after slaking to a dry powder, supposing the measure to be filled with all possible accuracy, an error may be made to the amount of 6 or 7 per cent. on the smaller volume; and there is a liability to error to a like amount in measuring the lime in the state of paste[‡]; both these methods, also, are attended with inconveniences in practice. The slaked powder in windy weather is too fine to be dealt with, and a considerable amount of unnecessary labour would be entailed, whether by measurements in this condition or in paste. The best method would appear to be to determine the weight of a given volume, and then, with reference to this weight, to calculate the requisite volume in lump to supply the required actual or absolute amount of lime for a certain bulk of sand.

The proportions for the two in volume being thus determined on, measures of wood may be made to allow of the two ingredients being added in the requisite quantities without the necessity of fractional estimations. To measure out the lime wholly by weight would not only be inconvenient in practice, but would yield to the merchant an advantage in return for imperfectly burned lime.

With cements, which are always supplied in the state of powder, and are sent on to the works in measures of definite capacity, the mode of measurement by volume is also obviously the most convenient. The only precautions that appear necessary are, that the quantity mixed at one time shall not be larger than can be used up before the mortar begins to set, and that the weight of a given bulk is that which belongs to the description of cement in use.

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[*] Pasley on Cements. Art. 284.

[†] Pasley on Cements. Art. 298.

[‡] See Results in Table XIV. Pasley on Cements.

It is necessary to observe, however, that the test of weight cannot alone be relied on, either with limes or cements. Cements may be of very inferior description and yet give a correct weight. It must be regarded only as a partial check on systematic curtailment of the quantity which the buyer should receive when he purchases a bushel or a yard of the material. An imperfectly burned lime might, by the quantity of raw stone present, make up the weight deficient through air slaking, but the manufacturer will never wilfully underburn his lime, because if sold in lump it is immediately detected, and if he has to supply it ground, the cost of reducing unburnt stones to powder would far more than compensate for the trifling saving he would effect in fuel. What is most to be apprehended is, that he will decrease the cost of grinding by allowing the air to do the hardest part of the work, and thus at the same time increase the bulk of his lime. Purchase by weight would lessen the extent of the injury thus done to the consumer, but the method would be too inconvenient to become customary.

With Portland cement the manufacturer likewise gains by selling an inferior material in point of weight, and that in two ways. Perfectly burned Portland cement is as hard as a vitrified brick, and in this condition the wear of machinery and the labour of grinding is very large. If imperfectly burned it is much softer, and in a given bulk there is less cement; the high temperature necessary for perfect burning causing great shrinkage in the raw material.

The test of weight becomes therefore some safeguard against inferior material both with limes and Portland cements, though not a perfect one.

The specification should state that a given volume of the material shall weigh a certain number of pounds, and the bulk supplied should be occasionally checked by ascertaining the relation between volume and weight. With limes to be employed on large works, where grinding is considered necessary, it is better to specify that they shall be ground on the spot.

The condition of the Roman, Medina, and Atkinson's cements cannot be tested by their weight in the same manner, but fortunately there is not the same necessity for it. They increase very little in bulk with exposure, and, therefore, as far as accurate apportionment of ingredients is concerned, it will be sufficient to measure so many bushels of sand against so many of the cement, according to the size of the cask or sack containing the latter. As these cements set, when fresh, in a few minutes, the test of energy in this respect can readily be applied, and an opinion be formed of the quality in a day or two. If Portland cement, however, sets very quickly it is to be distrusted, the quickness of set depending very much on the quantity of underburned material present. It is advisable, indeed, to give Portland cement a considerable degree of exposure before employing it, to [deprive it of this property, as well as of a tendency, to which it is liable, to break up after some months. Owing to the slowness with which the atmosphere produces deterioration on this cement, it is by far the best to employ in repointings and in small repairs, where the same cask of material may be in use for many days or even weeks, and be liable during all this time to constant exposure. For the same reason it is, perhaps, the best cement to export to our colonies, and the more so because the extra expense incurred in its purchase, as compared with other cements, forms but a small addition to the total cost when the carriage is included and the cement has arrived at its destination. A time, however, at length comes when the Portland cement, with exposure, becomes perfectly inert, and this time will arrive with it quicker than with Scott's cement, which will set well as lime, when it is too far injured to be classed as cement.

Scott's cement will increase in bulk by the action of damp air as the limes do, but far less rapidly; there is not, however, the same danger of this property being unfairly taken advantage of, because the loss of setting properties is very apparent after exposure.

Both it and Portland cement, like the Roman, Medina, and Atkinson's cements, can, in compounding mortar, be measured out of the packages in which they are delivered against so many bushels of sand.

It may appear to some, that the value of modes of procedure, sufficiently obvious, has been insisted on unnecessarily, but all those who have had practical experience in works will be aware, that though their importance is recognised in words, it is not in practice. The workman compounds his mortar pretty much as he chooses, or as his own immediate employer may direct if by so doing he does not increase his own labour; and as Sir Charles Pasley states, "actual measurement is not employed at all, the proportions of the ingredients being left to the tact or sagacity of the labourers who make the mortar, or if measure be used the rudest sort only is employed, that is, shovelsful or barrowsful." He considered that greater precision both in specifying and compounding mortar was much to be desired.

9.—On Proportioning the Ingredients of Mortar.

It has been shewn, that so far as can be judged from the contradictory opinions of men eminent as builders and writers on constructions, and from the few experiments made on the point, it matters little whether the sand employed for mortar is course or fine, or obtained from pits, or the beds of rivers, or from the sea; but that it ought to be free from all dirt and clay; and that of two sands equal in other respects, the more angular will make the stronger work.

It appears, too, that the only accurate mode of estimating the lime to be mixed with a given quantity of sand is by weight—or at least with reference to weight, though the actual measurement may be effected by volume.

It was necessary to decide on these points before considering the proportion of sand, which, for economy's sake, could be added to mortar without depriving it of resistance to a degree not compensated for by the saving to be effected. Before doing so, it may be well, also, to examine the proportions of the two ingredients in some of the old and recent mortars which have been analysed, and those which the present practice of architects and engineers gives sanction to, as this will show that I am proposing no alarming increase in the amount of lime.

In estimating the relative quantities of sand and lime in the mortars included in the table following, the lime has been reckoned at 50lbs. the cubic foot; the sand at 100lbs. In the case in which two numbers are given, the smaller or the larger proportion of sand results, according as the silicates present are assumed to have formed a portion of the lime, or to have been added with the sand. The term "air mortar," used in these cases by M. Berthier, does not necessarily imply that the clay found in the mortar did not form a part of the limestone used in its preparation, and it should, of course, be reckoned as a portion of the lime, if not subsequently added.

TABLE XX.

Shewing the proportions of sand and quicklime, estimated by measure from the kiln, of various ancient and recent mortars.

No.	Approximate Date of Employment.	Nature of Mortar.	Volume of Lime.	Volume of Sand.	Situation or Character of Work and Authority.
1	Not stated .	Hydraulic.	1	6	Old Roman. Dr. John.
2	1st century .	Air mortar	1	1	Tower by Agrippa,
3	Do. .	Do.	1	$2\frac{1}{4}$ to $2\frac{1}{2}$	Wall of Tower by Agrippa.
4	Do. .	Pure Lime	$1\frac{1}{3}$	1	Roman Tower, near Boulogne. Capt. Smith, Madras Engineers.
5	Do. .	Feebly hydraulic .	1	1	Old Town Wall, Rochester. Sergeant Hartley.
6	13th century.	Hydraulic.	1	4 to $4\frac{3}{4}$	Cathedral of Brandeburg. Dr. John.
7	Do. .	Air mortar	1	3 to $4\frac{1}{4}$	Buried foundations of St. Peter's, Berlin.
8	15th century.	Pure Lime	$1\frac{3}{4}$	1	Pagoda, Tripatty. Capt. Smith. Madras Engineers.
9	Do. .	Do.	1	1	
10	16th century.	Hydraulic.	1	$6\frac{3}{4}$	Castle at Berlin. Dr. John.
11	Beginning of 17th century	Pure Lime	1	1	Mohammedan Tombs. Captain Smith, Madras Enginrs.
12	Do. .	Do.	1	6	Tomb at Golcondah.
13	End of 17th century .	Do.	1	4	St. Peter's, Berlin, exterior joints. Dr. John.
14	Do. .	Do.	1	$3\frac{1}{7}$ to $3\frac{1}{4}$	Do., interior joints.
15	Beginning of 18th century.	Do.	1	3	Dutch Tomb. Capt. Smith.
16	?	?	1	3	Juliers, Bastion of Fortress. Sergeant Hartley.
17	Beginning of 18th century.	Feebly hydraulic .	1	4*	Chatham Dockyard Boundary Wall.
18	Beginning of 19th century.	Hydraulic.	1	1	Eastbourne and Bexhill Martello Towers. Capt. Scott.
19	Do. .	Feebly do.	1	1	Chatham Fortifications, and Footing of Railing in Brompton Barracks. Sergeant Hartley.
20	Do. .	Hydraulic.	$2\frac{1}{3}$	1	Trèves. Dr. John.
21	Recent . .	Feebly do.	1	5	Victoria Docks. Mr. Clegg.
22	Do. .	?	1	10	Railway works at Sydenham.

* A puzzuolana used for sand, in whole or in part.

Observations on Table XX.

The views of writers on the employment of sand, however discordant, do not disagree nearly so widely as the proportions found in the above table. The smallest proportion of sand used was less than half the volume of the lime; the largest ten times its volume. Between these limits there is every variety of proportion, apparently without reference to the quality of the lime, or any peculiarity of situation.

Davy in his work on Artificial Foundations, informs us that "From observations recently made it was found that 72 bushels of stone lime required 18 yards of sand, making good larried mortar;" which for one part of lime gives five and a half parts of sand by volume. This was a considerable advance on the proportion of sand required by the specifications of his time, though equalled or exceeded in some old mortars; but it was reserved for these days of large contracts to discover that good mortar can be made with ten parts sand to one of lime, that is nearly three times as much as our architects or engineers have yet ventured to specify, as may be seen by the examples given in the following table: Those dated before 1823 are from Davy's well known work on Foundations; the later ones are chiefly taken from Donaldson's work on Specifications, recently published.

TABLE XXI.

Shewing the proportions of quicklime from the kiln, and sand, specified in recent works.

No.	Nature of Lime.	Volume of Quick Lime.	Volume of Sand.	Date of Employment.	REMARKS.
1	Not stated .	2	3	1812	London practice, according to Peter Nicholson.
2	Chalk . .	2	3	1820	London practice, according to Davy.
3	Dorking grey chalk lime .	1	3½	1851	London practice. Dempsey's Builder's Guide.
4	Dorking . .	1	2	1861	London and Woolwich R.E. District.
5	Brixton . .	1	2	?	Stockport Church, Cheshire.
6	Not stated .	1	2	1825	Messrs. Grout, Baylis, & Co., Steam Mill, Yarmouth.
7	Dorking grey lime . .	1	3	1825	Do. do.
8	Do.	1	3	?	Bankruptcy Court, Basinghall Street.
9	Merstham grey lime .	1	2	?	House in Orton's Buildings, Southwark Bridge Road.
10	Dorking . .	2	3	1827	Turkey Street Bridge, Enfield.
11	Halling . .	1	2½	?	Greenwich Railway.
12	Dorking . .	1	3	?	London and Birmingham Railway.
13	Merstham or Dorking .	1	3	?	Watford Tunnel.
14	Grey lime .	1	3	1830	Tothill Fields Prison.
15	Lias . . .	1	3	1830	Do. do.
16	Plymouth .	1¼	3	1836	Exeter Market, Devon.
17	Aberthaw Lias . . .	1	2 to 4 according to situation	?	Berkeley and Gloucester Canal.
18	Grey lime .	1	3	1841	New Royal Exchange.
19	Fulwell lime.	1	3	1847	High Level Bridge, Newcastle.
20	Fresh stone lime . . .	the usual* proportions.		1848	University Hall.
21	Roach lime .	1	2	1848	Lunatic Asylum, Omagh.
22	Barrow lime.	1	3	1849	Gardener's College, Dalby Hall.
23	Stone (grey ?) lime . .	1	2	1849	Hants and Wilts Lunatic Asylum,
24	Aberthaw .	1	1	about 1850	Government works at Bullpoint.
25	————	1	6	?	Maisons Rue de Rivoli, Paris. 1 cube metre of sand to ·33 cube metre of SLAKED lime specified.
26	Stone (grey ?) lime . .	1	2	1851	National Schools, Margate.
27	Dorking lime	1	2	1855	19, Grosvenor Square, London.
28	Dorking or Merstham lime . .	the proper* proportions.		1855	Wellington College, Sandhurst.
29	Grey lime .	1	3	1857	Shop and Warehouse, Fetter Lane.
30	Barrow lime.	1	1 & 1½ cinder	1857	Granary at Leeds.
31	Do.	1	2	1858	Viaduct, Bardsey Bridge.
32	Aberthaw .	1	2½ to 3 according to situation	1860	Holyhead Breakwater.
33	Grey lime .	1	2	1861	New Fort at Gosport.
34	Blue Lias .	1	3	now erecting.	New Westminster Bridge.

* These are the words used in the specifications.

Observations on Table XXI.

Davy admits that the French are considerably in advance of us in researches on this subject; but he says "the reputation of the English builders for *practical experience* in the manipulation of mortars is, on the other hand, well known and appreciated by all those whose attention has been directed to these important investigations." He considers that the proportions given from his work (Nos. 6, 7, and 10 are amongst the examples), exhibit a tolerable agreement with each other, and that they are grounded upon careful observation and great practical experience. Since, however, with one and the same lime the proportions vary from one and a-half sand to three sand for one of lime; and it was according to his own statement found that it required five and a-half parts sand to one of lime, to make good "larried mortar," we may reasonably hesitate to yield at once to the conviction that the specifications of our English architects and engineers are based upon the close observation for which he gives them credit, and it may, perhaps, be thought somewhat hard on those who contracted for University Hall, that they were not informed by its eminent architect whether they might adopt the theoretic proper proportions, ranging from five to seven of sand to one part of lime from the kiln, or whether they would be certainly confined to a range of one and a-half to three parts sand, and within these limits have to conform to the view his clerk of the works might take of the matter.

The specification for Wellington College affords an amusing example of the want of that careful observation which Davy claims for our authorities in building matters, whether we view it by the light of their own precepts as given in Table XXI or, by that of the builders' practice as conveyed in Table XX.

In deciding on the proportion of sand which may be ventured on with different limes we should consider the effect which will be produced on the strength of the brickwork by variations in the resistance of the cementing material. So long as the joints of masonry and brickwork are weaker than the stones or bricks which form the bulk of a revetment, the strength of the wall (using that expression in a general sense) will increase proportionally with the strength of the cement employed, until they are nearly equal in resistance, when any further increase in that of the binding substance will be comparatively of smaller value. We say nearly equal, because when a bonded wall, built in mortar much weaker than the brick, is broken, the fracture is constrained to follow a longer path than when the work is put together without breaking joint. The aim of the engineer should therefore be to approximate by the cheapest mode to such an equality of resistance between the components of his structure (between the material in which the blocks of stone or brick are bedded and the blocks themselves), as will produce a straight fracture when subject to a transverse strain, and when that point is reached to improve them conjointly. It must be borne in mind, however, that as the proportion of sand is reduced from four to three, from three to two, and from two to one, the expense of the mortar is generally increased in a largely augmenting ratio.

Now, with reference to the fat limes, the resistance attainable with 1 part of sand to 1 of lime from the kiln bears but a small proportion to that of a weak stock brick, probably it would never exceed $\frac{1}{15}$th of it in the inner portions of massive masonry. By the addition of 1 part more of sand, the resistance of the mortar, whether to longitudinal or transverse strain, would not be reduced by more than $\frac{1}{6}$th, and would still have a resistance equal to $\frac{1}{18}$th of that of such a brick; with three parts (see Table IV. and V.) it would only descend to $\frac{1}{20}$th of the resistance of the bricks. The expense, however, of the mortar, reckoning the lime at 8s. per yard, and sand at 2s. 6d., would by adding 3 parts sand to the lime instead of 1 be reduced some 38 per cent. If the lime were of the Dorking or Halling quality, the resistance with 1 part of sand might be brought within $\frac{1}{5}$th perhaps of the strength of the brick, and the addition of another part would not sink it below $\frac{1}{6}$th or $\frac{1}{7}$th; and as the saving effected by using 2 parts of sand instead of 1 would be upwards of 30 per cent., the use of 2 parts can hardly be objected to, and it will be seen that this is the quantity specified in the London and Woolwich War Department schedules. The same remark would apply to the best Sussex lime of Lewes, in a less degree, however, because the mortar of that lime would approach, with 1 of sand, within one-half of the resistance of the bricks, and an extra dose of sand might reduce it to nearly one-third. Perhaps 1½ sand might be used with it, and 2 parts should not be exceeded; the latter quantity has, I believe, been specified for recent works at Gosport. The Lias lime, as it contains within a given volume one-half more lime than grey chalk lime, and is a stronger lime than that of Lewes, might be used with 2 parts without too great a loss of strength.

To be precise we may conclude, that with hydraulic limes such as the Lias (weighing 50lbs. the cubic foot), 2 cubic feet of sand may be added to 1 cubic foot of lime; that with feebly hydraulic limes, such as the Dorking and Halling grey chalk limes, 2½ cubic feet of sand may be added to every 50lbs. of lime; and in the case of pure limes, if we are compelled to use such miserable stuff, we shall not be losing much in resistance if we increase to 3 cubic feet of sand for every 50lbs. of the lime.

With respect to the cements, the Roman cement would probably equal the resistance of weak stock bricks, with 1¼ or 1½ parts sand; with 2 parts (see Tables XIV. and XV.) the loss of strength is too serious to be disregarded, and therefore the proportion should be either 1 or 1½ parts sand to 1 of cement powder. Scott's cement will equal the strength of the weaker bricks with 4 parts sand; and the best Portland cement would probably equal it with 5 or 6 parts, but only the best. So long therefore as bricks having no more resistance than ordinary London bricks are used in building, Scott's cement may be used with 4 parts; Portland—of the quality obtainable from Messrs. Lee, or Boorman, or White—with 5. If the bricks were made stronger or a compact stone used, these quantities of sand should be decreased for the cement to 2 or 3 parts. It is not recommended, however, that a less quantity than 2 parts shall be used, because with 2 parts sand the loss of strength is small, and probably what is lost in this way is compensated by the greater certainty of the joints being good.

The proportions here recommended apply only to works above the surface of the ground or free from the action of a body of water. For hydraulic purposes and foundations, 1 part sand to 1 part lime is as much as should be admitted;

but with cements the proportion may be increased to 2 parts, unless actually in contact with water, when 1 part should be the limit allowed.

As compared with the practice of our leading architects and engineers in drawing out their specifications, the proportions here recommended are not such as to call forth objections, but doubtless the quantity of sand proposed is very small as compared with that which would result from using only a sufficient paste of lime to fill its voids, or as compared with the excessive quantities which it has been customary, since the commencement of our railway constructions, to introduce into mortar. This much, however, must be allowed, that if it is proper to specify 2 sand to 1 lime it is also proper to enforce that these proportions shall be adhered to.

10.—On the Proper Employment of Mortars.

We must now proceed to the consideration of the manner in which mortar should be employed. The first point, to which attention must be directed in its use, is the necessity of thoroughly wetting the materials it is intended to bind, particularly if they are of a dry absorbent character. The second point, that the mortar shall be as stiff as it can be used without inconvenience, and without danger of the joints remaining unfilled when the bricks and stones are forced home. The third, to prevent rapid desiccation which, with hydraulic limes, produces very injurious results.

It is sometimes thought that the precaution of wetting bricks is unnecessary with lime mortars, and excepting in very hot weather, when the bricklayer finds their warmth and dryness inconvenient, it is rarely done. Cements, on the other hand, are supposed to suffer in their adhesion if the bricks are not wetted, and consequently it is usual to specify that they shall be so treated. The following Table, however, will make it clear that if the hydraulic lime mortars require to be kept moist to secure their induration, as all writers assert, it is nearly if not quite as necessary to make the proviso, that the bricks shall be wetted when used with lime mortars, as when used with cement. The bricks, before being weighed, were left in a room on a stone floor; and, after immersion in water till air bubbles had ceased to rise from them for some minutes, they were again weighed, when they ceased to drip.

TABLE XXII.

Showing the weights and absorptive properties of various kinds of bricks.

Description of Brick.	Weight when air dried.		Weight when saturated		Weight of water absorbed.		Names of Makers, &c.
	lbs.	ozs.	lbs.	ozs.	lbs.	ozs.	
Cutters	5	5·3	6	4·6	0	15·3	Messrs. Randell, Maiden Lane.
Do.	5	10·6	6	10·2	0	15·6	
Paviours	5	12·42	6	2·42	0	6·0	Messrs. Lee and Sons, Upper Clapton.
Seconds, No. 1	4	9·2	5	15·9	1	6·7	Messrs. Rhodes, Dalston.
Do.	5	2 8	6	3·0	1	0·2	
Seconds, No. 2	5	8·1	6	3·6	0	11·5	
Do.	5	8·2	6	3·9	0	11·7	
Seconds	5	9	6	7·9	0	14·9	Messrs. Lee and Sons, Upper Clapton.
Paviours	5	9·6	5	13·0	0	3·4	Messrs. Rhodes, Dalston.
Do.	5	7·9	5	12·6	0	4·7	
Malm Paviours	5	12·42	6	2·42	0	6·0	Messrs. Lee and Sons, Upper Clapton.
Do.	6	0·62	6	7·3	0	6·68	Chatham neighbourhood.
Hard Seconds	5	10·6	6	6·6	0	12·0	Messrs. Rhodes, Dalston.
Do.	5	9·9	6	5·2	0	11·3	
Pickings	5	10·8	6	9·6	0	14·8	
Do.	5	10 9	6	10·2	0	15·3	
Do.	5	3 72	6	0·1	0	12·38	Messrs. Lee and Sons, Upper Clapton.
Second Malms	5	8·73	6	2·0	0	9·27	Chatham neighbourhood.
Rough Stocks, hard burned	5	1·3	5	5·4	0	4·1	
Grey Stock, hard burned	5	8 5	5	13·17	0	4·67	
Picked Stocks	4	14	5	12	0	14	
Do.	5	0·31	5	14·5	0	14·19	
Grey Stock, ordinary	5	14·83	5	11·04	0	12·21	
Do. do.	5	2·72	5	10·93	0	8·21	
Soft Grey Stock	4	11·6	5	10·93	0	15·33	
Red Stock brick	6	0	6	11	0	11	Messrs. Randell, Maiden Lane.
Machine pressed Red Stock	6	12·73	7	0·53	0	3·80	
Darland Builders	5	9 19	6	2·4	0	9·21	Near Chatham; a red brick.
Do. Red Stock	6	0·3	6	14·42	0	14·12	Near Chatham.
Suffolk White	6	5·56	7	6·0	1	0·44	
Aylesford White	5	13·5	6	14·0	1	0·5	
Perforated brick	4	12 0	5	8·7	0	12·7	Patent Brick Company, Great Northern Railway.
Do. do.	4	13·75	5	13·55	0	15·80	

Observations on Table XXII.

The mean weight of water absorbed by the bricks experimented on amounts to nearly 12ozs. per brick, and it would appear from the results given, reasonable to assume that in the general way of building near London it will not be less than 10ozs., particularly when the bricks are made on the spot, and at once put into the work without previous exposure to the air. Excepting indeed in the case of a few bricks of very superior description, or of stocks specially selected for their hardness and semi-vitrified appearance, the quantity of water absorbed by the ordinary building bricks experimented on, is, in few instances, less than this. It is estimated that a rod of brickwork requires 4,300 stocks and 86* cubic feet of mortar, of which we may assume about 39 cubic feet to be of lime, if the lime be grey, and our London schedule specifies reasonably. The 4,300 bricks if dry, will absorb 43,000ozs. of water, and the 86 cubic feet of mortar, will, if made of average lime, and of average consistency, require about 32,000ozs. of water in its preparation, of which 8,000ozs., or thereabouts, will enter into chemical combination with the lime, and quite 2,000ozs. be lost by evaporation. Under such circumstances we have therefore some 22,000ozs. of water in the mortar joints, free to pass off to the bricks, and these have a power of absorbing 43,000ozs.†

The conditions in brickwork are of course less favourable to absorption than when the bricks are actually immersed; but on the other hand, evaporation from the brick will occasion some loss of moisture (and in thin walls such loss will be considerable), before the mortar can set. In an experiment tried at Chatham on single bricks placed one on the other, the joints being subjected to a pressure of 56lbs. for two hours, and their mean absorption when immersed being 15·7ozs., the bricks drank in on an average 2·7ozs. each. Taking two-thirds of this to represent the degree to which the stock bricks, of the absorptive power above assumed would have imbibed water; we have, without reckoning that of the smaller faces, 1·8ozs. as the weight of water which would be taken per brick in a 4½-inch partition in the same time if similarly weighted—or for the rod 7,700ozs., being in two hours more than one-third of the total amount of water which the joints contain.

Such calculations are of course very rough approximations to the actual truth, but they are sufficient to show that under such circumstances the mortar in contact with the bricks cannot retain the moisture which is required for the induration of hydraulic limes; and, indeed, although few English engineers or architects now think of specifying that the materials used with lime mortars shall be wetted, those who have paid attention to the subject have well known its necessity and clearly stated it.

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* The quantity of mortar in a rod of brickwork has been variously estimated between 70 cubic feet and 90 cubic feet. It evidently depends somewhat on the thickness of the wall and the form of the brick, whether made with a hollow on one side or not, as well as on the closeness of the joints, and the extent to which the joints are flushed up. The quantity here assumed is purposely taken high, in order not to employ a case favourable to the argument advanced.—H. S.

† Lieutenant Colonel Fisher, R.E., made a long series of careful experiments on the absorptive properties of bricks, and on the quantity of water free to evaporate from given bulks of mortar. The bricks employed were Lymington, Grey Stocks, and Taunton bricks; and the limes, Lias, Plymouth pure, and Plymouth hydraulic. From these experiments it would appear that the mean quantity of water which the number of dry bricks contained in a rod of brickwork can drink in when immersed in water is 40,000 oz., and the quantity of water which can evaporate from the mortar in a rod of brickwork is 27,000 oz. The experiments are given in full in No. 15, Royal Engineer Establishment Papers.

Partington in his "Complete Builders' Guide" says that "few workmen are sufficiently aware of the advantage of wetting bricks before they are used, but experience has shown that works in which this practice has been attended to, have been much stronger than others in which it has been omitted." Amongst the circumstances which contribute to the speedy ruin of modern buildings he places the use of mortar "with dry bricks, and not unfrequently with warm ones."

Rondelet, in his "Treatise on the Art of Building," says, "that in order to make the mortar unite better with the stones, it would be of advantage that the workmen should have near them a great bucket or trough of water, in which they should soak the stones before laying them, and a basket with open wicker-work for the spalls, which should be soaked in the same manner before mixing them with mortar. This mode of proceeding, which I have seen practised in many parts of Italy, is excellent for works which are to contain water, &c."

Vicat writes, "the whole secret of good manipulation and right employ is condensed in the following precepts: "*stiff mortar and materials soaked.*" Our bricklayers, on the contrary, seem to have taken for their motto, "*dry bricks and drowned mortar.*"*

In an appendix he adds—"It is true it is sufficient to water the compact stones, such as granite, quartz, mill stone grit, limestone, marble, &c., at the moment of using them; but a mere aspersion will not answer in regard to spongy and absorbent surfaces, such as bricks, the soft or arenaceous limestones, sandstones, &c.; when we have such materials it is necessary to moisten them without ceasing, and to keep them in a permanent state of imbibition."†

Or to come to later authorities, Drysdale Dempsey in his "Builder's Guide," published in 1851, says—"One other rule has to be observed, and we reserve it for this last and separate and emphatic statement, to show our estimate of its importance, in order to produce good brickwork, which is this:—that the mortar should be as thick as it may be, or nearly approaching the solid form, as is consistent with the degree of plasticity essential for its proper distribution and penetration into the joints, while the bricks should be thoroughly wetted on the surface. By these means the adhesion between them is rendered the more perfect, and the subsequent amount of shrinking and settlement is reduced to a minimum."

There is, however, another and equally strong reason for thoroughly wetting bricks in buildings which likewise affects lime as much as cement mortars. New bricks are always covered with a coating of dust and fine sand; and unless this coating is washed off, it intervenes between the bricks and the mortar, and frequently entirely destroys the adhesion. Strong brickwork cannot, therefore, be executed either in lime or cement mortar, unless the bricks are not only damp, but have actually been washed. Colonel Totten, of the United States army, remarks, in his instructions to Colonel Lee, on the subject of experiments against casemate embrasures:—"In the late firings against brickwork from a 42-pdr., it was noticed that there was a separation of bricks from mortar very generally, as the limit to the breach caused by the shot; and it was certain that if the cohesion had been greater the effect of the shot would have been materially less." "The want of cohesion was due, as seemed to me, beyond any doubt, to the interposition of dust, sometimes quite free, but, perhaps, more generally composing a layer slightly cohering to the body of the bricks. The process of laying must be to cause every brick to be thoroughly soaked in water, and to be laid the moment it ceases to drip."*

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* Smith's Translation of Vicat, p. 231.

† Smith's Translation of Vicat, Appendix LXIII.

In an experiment made at Shoeburyness with shot and shell fired from an 80-pounder Armstrong gun, against an experimental brick revetment, before the Defence Commission, not only were the bricks blown out without a particle of mortar adhering to them, and generally without a fracture on them, but about 3 feet from the ground the whole of the under part of the revetment was blown away for a length of 12 or 13 feet, and to a depth of 5 or 6 feet, leaving an entire horizontal course of bricks at the upper limit of the fracture, with an even course of cement adhering to it, precisely as if it had been laid on as stucco after the lower part of the wall had been removed. To have allowed of such a clean separation, leaving a horizontal beam of bricks with so long a bearing standing, and evenly coated with mortar underneath, some unusual interference with the adhesion of the mortar must have been at work. As the wall was built on a site of which the soil consisted of fine sand it seems probable that the line of separation marked the termination of one period of the work, and that before the next was commenced, a layer of the fine sand had been deposited on it by the wind.

Colonel Totten thinks that his orders with respect to wetting the bricks could be carried out without extra expense by an "arrangement easily devised," but Vicat states,† "the soaking of the materials is evidently an addition to the labour, which should be taken into account in the detailed estimates," and doubtless, though the extra expense when water is abundant need be trifling only, there must be some allowance made for it beyond what is now paid for brickwork. It is certainly, however, well worth consideration whether, if the difficulties in the way of carrying it out were greater, they ought not to be surmounted, more especially in extensive fortifications constructed with bricks burned on the spot, and built into the work as soon as they have left the clamp or the kiln—often, indeed, before they are cold. What difficulties there may be in effecting it are not so much raised by the master builder—for a trifling extra price to cover the expense of the wetting would satisfy him—as by the bricklayer, whose day's labour is considered of the same value, whether he works with wetted or dry bricks, and bricks "just ceasing to drip" are so hurtful to his fingers that he has a decided objection to handling them in that condition. Colonel Totten, indeed, in continuation of his former remarks, adds, "but I must caution you that, as this will be in some respects a disagreeable process to the masons, they will neglect it or do it improperly, unless it be imperatively and perseveringly insisted on." The best plan, therefore, would be to wet the bricks for them by trustworthy workmen, employed and paid by Government. Probably a soldier, who has been accustomed to obey orders to the letter, could best be depended on in such a case. Vicat recommends, in large works, watering the bricks whilst in the stack with a fire engine, so that they may reach the mason's hands in a soaked state. It was thus, he states, that M. Inspector General Deschamps, at the Bridge of Bordeaux, watered the bricks piled up on the service bridges.

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* Corps Papers, New Series. Vol. VIII.

† Smith's Translation of Vicat, Appendix LXIII.

A specification, therefore, should provide for wetting the bricks whether lime or cement mortar is to be used; yet there is a difference between them in respect of water, which should be well understood by every builder. It consists in this :—the "limes," when reduced to powder, as already stated, and made into a stiff paste with water, slake and fall abroad more or less perfectly, generally becoming a fine bulky powder, which requires a fresh addition of water to make it into mortar; and the cements, when similarly treated, consolidate with the water first added, and must be used before the slaking takes place. In the one case the slaking, as a general rule, takes place immediately, or shortly after the water is added, and the setting occurs subsequently, perhaps, many months after the mortar is used; in the other, the slaking and setting are simultaneous, and take place after comparatively short intervals. With the limes it will be seen there is a supply of water in the mortar (all, in fact, necessary to bring the slaked dry lime powder and sand to a paste) over and above that which has chemically combined with them in the act of slaking; with the cements, a portion of the water used in making them into mortar is required to satisfy their chemical wants. The first description of mortar when a drain is brought upon it by its being placed in contact with a dry absorbent surface, loses water, which has to perform a secondary part in the induration; the cement mortar, under such circumstances, loses water absolutely essential to its consolidation, and without which it perishes. In neither case will there be proper adhesion ; and in neither case, if the lime is a strong one, will the induration of the mortar itself become perfect in the absence of moisture over and above what will be required to unite chemically with it; but comparatively, the cement will suffer most since there is neither a reservoir of what, for the time at least, is spare water, to draw upon, nor, with its somewhat gritty particles, that strong retention of water which is found with the unctuous and plastic lime mortar.

The result of this is that a bad lime mortar joint may show fair outwardly, when the bad cement joint will grow crumbly, and betray the mischief done; or should any of the work executed in lime mortar be pulled down in the progress of a building, the want of the wetting is not perceived, for the mortar takes a long time to set, and no adhesion is expected, after short periods; but with the cement joint a failure is evident at once, because a few hours or a few days should impart to it a respectable resistance.

It would seem, indeed, that little resistance can be expected from our lime mortars in this country, however long they may have to set, or provision would not so often be made for cleaning old bricks.

In illustration of the other cause, rendering wetting necessary, may be mentioned also the brick masonry of an old wall now being destroyed in Chatham Dockyard; it formed the North boundary of the original enclosure, and was probably built in 1622. Though the mortar is good and of an expensive kind, being mixed with a large proportion of excellent puzzuolana, instances of non-adhesion from the effect of the dust on the brick are easier to find than instances of good adhesion, and the same defect is noticeable in most walls. It is manifest that the interposition of such a layer must be fatal to the adherence of both limes and cements. This cause of weakness in construction has apparently attracted less notice than the injury done by want of sufficient moisture. The only writer, indeed, excepting Colonel Totten, who, as far as I remember to have noticed, has any remark on it, is Partington. This author says, that "to make strong work, the bricks ought to be soaked in lime water, and freed from the dust with which they are commonly covered." *

The next point to be considered is the degree of consistency which mortars should have when used. Treussart preferred that they should be rather thin than stiff, but experiment indicates that, so far as the resistance of a good joint is concerned, the stiffer the mortar the stronger will be the joint.

The following Table illustrates this. It is taken from Vicat's work.

TABLE XXIII.

Mortars, compared with reference to the consistency given to the mixture of Lime and Sand.

Proportions.		Absolute resistance of the mortars at the age of 14 months, per square inch.						OBSERVATIONS.
		Exposed to the air.			Buried under ground.			
Eminently hydraulic lime, in paste, obtained by the ordinary extinction.	Granitic Sand.	Kneaded stiff.	Kneaded soft.	The same nearly liquid.	Kneaded stiff.	Kneaded soft.	The same nearly liquid.	
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
100	150	239·13	143·48	76·86	177·64	165·11	127·39	Each of these results is the mean of a number of experiments.
Rich lime 100	150	80·42	41·28	17.08	...	...	...	

Observations on Table XXIII.

As Vicat remarks, however, "It is quite evident that a very stiff mortar cannot be used with dry and absorbent materials. When we have materials of this kind, they must be watered without ceasing, and kept in a perfect and permanent state of imbibition." Raucourt de Charleville takes the same view—"One ought," he says "in general, to employ stiff mortars and wetted materials."

The danger to be apprehended in using very stiff mortar is that the mason will be less likely to fill all the joints with it. Mr. Page, consequently, in his specification for the New Westminster Bridge, provides that "the bricks shall be soaked in water, used clean, shall be closely bedded, and the mortar used sufficiently thin in the interior of the work to enable the workmen to flush the joints full without grouting, which is not to be used without the special directions of the engineer."

Though, then, the stiffest mortars will give the best results if the joints are properly filled, yet to secure that there shall be no vacant spaces left, they must be sufficiently fluid to be worked with ease.

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* Partington's "Builder's Guide," Art. Bricklaying.

It would appear also that grouting is but a poor substitute for good stiff mortar, and General Totten arrived at the same result. The next Table is from his work. To obtain similar joints with the grout, the bricks were supported in a box large enough to admit the proper quantity between each. The box was not disturbed until the grout had become quite stiff, and then the excess of grout was carefully cleared away.

TABLE XXV.

Shewing the comparative strength, after 10 months, of Grout and Mortar, the bricks being torn asunder, as in the experiments already given.

No. of Trials.	Measure of Lime or Cement to 2 Measures of Sand.	Resistance in lbs.	
		Of Mortar.	Of Grout
4	1 Lime.	30·12	17·19
4	1 Cement.	36·69	19·75

General Totten also employed grout consisting of lime and cement mixed, and including these, the average of all the mortars given in his Table is 31·78; and the average strength of all the grouts is 20·06. It may then be assumed that whenever grout can be dispensed with, and all interstices be filled with stiff mortar properly applied, it is better to employ the latter. A large quantity of water has the double disadvantage of causing cracks by the shrinkage of the mortar from its subsequent evaporation, and of leaving it very porous.

The next Table is from Vicat's work, and shows the necessity of keeping mortars of hydraulic lime moist until setting has taken place.

TABLE XXVI.

Mortars, compared in regard to the influence of desiccation.

Proportions.		Absolute resistance of the mortars when 22 months old, per square inch.		OBSERVATIONS.
Lime slaked by immersion. and measured in paste.	Common granitic Sand.	When exposed, after manufacture, in a loft of the temperature of 59° Fahrenheit.	At first put under ground, and afterwards removed into the open air by degrees.	
		lbs.	lbs.	
Hydraulic lime 190	150	92·23	165·68	Each of these results is the mean of a number of experiments.
Feebly hydraulic lime 180	150	44·12	73·73	
Common rich lime 180	150	45·55	51·24	

Observations on Table XXVI.

The table not only shews the extent to which mortars will suffer from a rapid desiccation, but that the injury is greater in proportion as the lime used is more hydraulic. With eminently hydraulic limes, indeed, Vicat estimates that there may be a loss, from rapid drying, of $\frac{4}{5}$ths of the resistance of which they are capable when they dry slowly. The reason of this has already been explained. The purely lime mortars suffer less because in the internal parts they merely dry under any circumstances, and a rapid desiccation only interferes with the crystallization of the carbonate of lime where the air reaches them.

It will be seen then that in hot weather, and especially in hot climates, the prevention of too rapid a desiccation becomes a point of great importance, especially where hydraulic limes are employed. Colonel Raucourt de Charleville recommends the use of straw mats for the purpose, which are to be suspended over the newly built masonry, and watered night and morning.

We have now examined the various points necessary to be considered in the preparation and use of mortars, and have only to enquire whether the advantages to be gained will compensate for the increased trouble and expense which the suggested improvements would entail. Before doing this, it may be well to recapitulate them to assist in judging of their feasibility. They are summed up in the following paragraphs.

1st. Cements should be used in preference to hydraulic limes, and hydraulic limes in preference to pure limes for dry masonry, as well as for hydraulic purposes; and in making a selection between them, first cost alone should not decide the question, where 1 or 1½ per cent. extra on the cost of the building will procure a great increase of strength.

2nd. That though there is not much difference in the results to be obtained from sands from different localities, they should be freed from all clay and dirt.

3rd. That in mortar for dry situations, for every 2 cubic feet of sand, 50 lbs. (equivalent with stone limes generally, to 1 cubic foot) of hydraulic lime from the kiln shall be employed; but that with cements of certain character, this quantity may be considerably increased, without notable loss in the resistance of a construction in ordinary bricks. It may also be increased to 3 cubic feet with pure limes without much injury to the strength of the brickwork.

4th. That for damp foundations and hydraulic works the above proportions of sand should be reduced according as the exposure to the action of water is more severe.

5th. That strong hydraulic limes, after the water for slaking them has been added, should be left covered with sand for 24 hours, at least, to complete the process on the overburned parts.

6th. That strong hydraulic limes, if not ground to a fine powder before slaking, should be ground either alone or mixed with sand under an edge stone; and that if ground alone, they should be afterwards mixed into mortar in a pug mill, though like the cements, they might, when first brought to a fine state of division by grinding, be efficiently mixed by hand in small quantities.*

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* Since the above was written, instances of failure from neglect of the precautions mentioned in this and the preceding paragraphs have occurred in works under the Royal Engineer Department.

The late eminent Engineer of the Liverpool Docks, Mr. Hartley, says of the Halkin Mountain hydraulic limestone:—" When I first used it, I was surprised to find that by

7th. That the materials with which the mortar is used shall be well wetted, and that bricks having a coating of slightly cohering sand or dust upon them, should have this coating washed off before being laid.

8th. That the mortar shall not be more fluid than is requisite to fill the joints and crevices, and that the miserable expedient of grouting should never be resorted to.

9th. That the brickwork or masonry in hydraulic mortar or cement should not be allowed to dry quickly.

12.—ON THE REASONABLENESS OF USING STRONGER MORTAR IN OUR REVETMENTS, &c.

It has been argued that it is of little use to strengthen our revetment walls and the buildings in fortresses, because nothing in the shape of masonry can resist artillery, but there is abundant evidence to show that the amount of fire requisite to produce a breach, all other things but the masonry being equal, is very different. Sir John Jones asserts that the walls of the South of Spain required twice as much firing to destroy them as the brick revetments of the North of Europe, and he attributes the difference to the superiority of the Spanish mortar. At St. Sebastian the distance of the batteries from the wall breached was 620 yards; at Ciudad Rodrigo, 570 yards. The revetment at St. Sebastian required 5000 shot to form a breach of 30 feet; at Ciudad Rodrigo, only 2080, for a breach of the same width; and it was noticed that the first was of good masonry, the second of bad. The tower at Bomarsund caused surprise by the facility with which its masonry was destroyed; the tower at Eastbourne, breached by Armstrong shot and shell, astonished the Artillery officers by the tenacity of its brickwork; and yet, as we have seen, though far superior to the mortar of the works fired against at Juliers, the Eastbourne mortar generally had not much more than one-half the strength of that of the Bexhill Tower (Table V) when exposed to a strain acting at right angles to the joint; and the mortar of the Bexhill Tower again (Table VI had not, in its maximum result, one-half of the resistance to compression of a selected specimen of well mixed Eastbourne mortar, the quality of the lime and the proportion of sand being similar in the two cases. Bad, however, as was the Eastbourne mortar generally, compared with what it might have been, it seemed pretty clear it was much stronger than the officers present—who must have judged from the wretched mortars usually met with—were prepared to expect, and doubtless it gave to the Armstrong guns a much tougher piece of breaching work, than the Juliers mortar gave to the Prussian guns.

The revetment at Antwerp caused the French 34 hours of firing to produce a breach, and we may assume the brickwork to have been of the ordinary description found in Northern Europe; this period would have been doubled according to Sir John Jones, if the revetment had had the resistance of the walls of the

its *great strength*, and a want of different treatment in its manufacture to any other stone I had used, it had thrust out several ashlars of 3 to 5 tons each, past the front of the wall for 1¼ inch. This difficulty I surmounted, but others seeing the uses I had put it to, adopted it in railway bridges, to their *great dismay*, for it threw down a serious quantity of work on two different lines by different contractors. I now understand it is better understood and in extensive use."—*Letter to the writer, dated 7th March*, 1859.

South of Spain; but, as we have shewn, the best limes cannot compare with the cements in strength, and probably if built in cement, three or four days' firing would not have sufficed for its destruction. It is usually considered that if in a revetment the vertical cuts be carried up two-thirds of the height of the wall, and a horizontal cut be made near the bottom, say three feet from it, the wall will fall. Now, according to an experiment made by Captain Fowke on an arch in a wall built in Scott's cement with 4 parts sand, half of which arch had been destroyed, it required more than 1 ton 8 cwt., acting with a leverage of 80 inches, to fracture the brickwork at the haunch, when the haunch was cut under so as to leave a depth of 39 inches of wall to support the weight. If a revetment 30 feet high, of the dimensions assigned by Vauban, were built in the same manner, and attempted to be breached as recommended by Artillerists, a horizontal cut, with vertical cuts to two-thirds the height of the wall, would not be sufficient to bring down the beam of brick above, so long as the counterforts remained. It may be thought that the concussions would crack the wall above so much as to destroy its cohesion in the longitudinal direction, but the breaching experiments I have witnessed have not led to this result, whether shot or shell have been used; and in the experiments made at Shoeburyness before the Defence Commission, as has been already stated, a brick beam 12 feet long was left standing without a flaw when the under part had been blown out. The revetment experimentally breached at Metz had counterforts 7 feet in length, 5 feet 4 inches wide at the root, and 4 feet at the tail, and the counterforts were 16 feet distant from centre to centre. It was considered that intervals of 30 feet might be left between the vertical cuts, and it was thought that even if it were practicable to fire salvos, the vibration in masonry extends to so small a distance from the centre of concussion that very little would be gained by it. Without great vibration, however, cuts at such distances would manifestly be insufficient to bring down a wall built like the upper portion of that at Shoeburyness, or that already alluded to, built by Captain Fowke, and the above intervals between counterforts might be greatly reduced with much advantage in point of strength and without increase of expense, as their thickness might be correspondingly diminished.

Making due allowance for the difference there may be between the resistance opposed by a wall to artillery fire, and the resistance opposed to longitudinal, transverse, and crushing strains, it can hardly be doubted that a revetment built in the manner I have recommended, with good cement and careful workmanship, would afford three times the resistance to a breaching fire that has been offered by the brick walls of Flanders, to which Sir John Jones alludes. Supposing, in fact, that in a siege it would, in consequence of the fire of musketry and wall pieces from the place, and other difficulties, require a day's firing with shot and shell to breach a revetment built in bricks and Halling or Dorking grey lime mortar, when the bricks can oppose to tearing and crushing forces resistances per square inch of 100 and 500 lbs. respectively, and the lime mortar resistances of 10 lbs. and 50 lbs., it is not unreasonable to assume that the wall will resist artillery fire twice and a half times as long, when the resistance of the cementing material to tearing and compressing strains is raised to an equality with that of the bricks, and becomes ten times as great as in the case of the wall built in such grey lime mortar.

If the walls of a fortress on Cormontaigne's system be built in grey lime mortar—1 lime to 2 sand—we may assume that the brickwork would form two-thirds of the whole expense. Taking the lime at 11s. per yard delivered, the sand at 2s. 6d., we may assume that the cost of the brickwork per rod would be £8 10s. The quantity of mortar required for each rod would be about 2·63* yards, and this would require something over 1 yard of lime and 2 cubic yards of sand for its preparation (= 2·4 yards mortar), being in all 17s. 6d. per rod for the materials of the mortar.

Calling the cement 1s. 1d. per bushel, delivered, packages included, and using with it 4 parts sand, which was the proportion used by Captain Fowke in the brickwork above alluded to, and assuming the 4 parts sand to yield 4 parts mortar, which it has been found to do, we should have for the cost of the 2·63 yards nearly 21s. 6d., or 4s. more than the cost of the grey lime mortar. To this, adding 2s. per rod for the improved workmanship recommended,† (and this it is believed would amply cover it with a cement which can be worked up in large quantities, in massive walls where there is little facework), and we have the cost of our rod of brickwork £8 16s. instead of £8 10s.; that is to say the brickwork is increased in cost about 3½ per cent., and the total extra expense of the whole work will be about 2½ per cent.‡

It cannot be doubted that this 2½ per cent. would in the long run be saved in the comparative absence of the necessity for constant repairs; but leaving this, and the possibility of building thinner walls, out of consideration, and leaving out of consideration also the serious contingencies which might depend on a place being able to hold out for another day or two, if we spend £360,000 to keep an enemy out of a place for 30 days we may well spend £369,000 to keep him out for 32 or 33 days.

Where caponiers are employed the necessity of good masonry is increased. It is useless to say that they may be so covered as to be safe from shot. The charge and elevation of ordnance may always be arranged to meet the difficulty, and with bad masonry, even a stray shot or two may go far to make a breach in a weak wall perforated with embrasures. Walls so perforated are very different from solid revetments backed with earth; these, if the masonry is of very moderate resistance, require that certain rules shall be followed for their destruction, and the blows must follow continued lines; but when the walls are not backed with earth, and are broken up by embrasures and loopholes into numerous angles, bad masonry soon becomes shaken throughout.

There is a case on record, indeed, of a revetment wall so badly built as to have been destroyed by shot not intended to hit it. An enfilade battery erected by the Austrians, against the face of the demi-lune and covered way of the citadel of Alexandria, in 1799, breached the face of the bastion on which these were directed and, although the besiegers were ignorant of what they had accomplished, this hastened the surrender of the place.

At Huningue, also, in 1814, the escarp of the enceinte was much injured through the trouée of the ditches of a hornwork by ricochet fire, which missed the adjacent branches aimed at. In the opinion of General Vaillant, a Carnôt wall would have been breached under similar circumstances.

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* Supposing the joints to have the necessary thickness only.—H. S.

† Which is really necessary in any case, whether for lime or cement work.—H. S.

‡ It is left to the reader to make the comparison with Lias Lime, or with Medina and Portland Cement.—H. S.

"Si l'on avait," writes a Military Engineer,* who made a study of mortars, "à construire des maisons, qui ne dussent avoir qu'un certain nombre d'années d'existence, comme on le fait en Angleterre, on pourrait choisir les mortiers et les matériaux dans cette intention, de telle sorte que toutes les parties de l'édifice manquassent ensemble." This gives us credit for a judicious apportionment of means to the end which we hardly deserve. Let us not have it supposed that our fortifications also are built on a 99 years' lease.

Mr. Burnell, in the preface to his work on Limes and Cements, says, "That which is to be desired above all things is to rouse the professions of engineers and architects from the apathy with which they treat such subjects as the one before us—the very alpha and omega of their business." His representations, however, have been as ineffectual as those of the distinguished men whom he follows. Smeaton long since explained, "It is not to be wondered at that workmen generally prefer the more pure limes for building in the *air*, because being unmixed with any uncalcareous matter, they fall into the finest powder, and make the finest paste, which will of course receive the greatest quantity of *sand* (generally the cheaper material) into its composition, without losing its toughness beyond a certain degree, and requires the least *labour* to bring it to the desired consistence; hence mortar made of such lime is the least expensive; and in *dry work* the difference of hardness, compared with others, is less apparent."

The workman, however, preserves his empire. Messrs. Ellis and Sons, of Barrow, sending some samples of their lime, at our request, remarked of one, that it did not command a ready sale, as the builders did not like it; yet it was the best lime we have met with in this country. A very excellent lime, far superior to the grey lime ordinarily met with in the London market, can be prepared from certain beds of chalk in this neighbourhood; but these beds are rejected as useless, because, like the Barrow lime, the lime from it does not slake readily, and loses its plasticity with a smaller proportion of sand than that from the purer beds.

It is a difficult matter to alter the practice of those who have grown grey in exalting "practical experience," and in the comfortable persuasion that the bricklayer knows best how to make good mortar, and can be trusted to make it.

"Old impressions," as Reaumur has well observed, "are with difficulty effaced. They are weakened, they appear unjust even to those who feel them when being attacked by arguments which are unanswerable; but the next instant the proofs are forgotten, and the perverse association resumes its empire."

Notwithstanding, however, all the obstacles in the way of better practice, I look confidently forward to the day in which we shall feel quite independent, as respects mortar making, of the workman's traditions. We have, indeed, already taken a long step towards it. Though brought up in the notion that mortar making was a mystery which required a long practical apprenticeship to master, we Military Engineers now gladly call in the assistance of the chemist, and consider his opinion a very useful check on that of the practical builder; and our younger brethren, commencing with an accurate knowledge of the principles which should regulate mortar making and mortar using, will feel still more strongly the necessity of insisting on the observance of the rules to be deduced from these principles, if they desire that their works shall prove lasting monuments of their skill in construction.

* Colonel Raucourt de Charleville.

PAPER IV.

ON THE ENGINEER OPERATIONS
CARRIED ON
IN NEW ZEALAND DURING THE WAR IN 1860-61.

EXTRACTED FROM REPORTS AND JOURNALS SENT BY COL. MOULD, C.B., COMMANDING ROYAL ENGINEER IN NEW ZEALAND, TO THE DEPUTY ADJUTANT GENERAL, ROYAL ENGINEERS.

MEMOIR EXPLANATORY OF THE NATURE OF THE COUNTRY ABOUT THE TOWN OF NEW PLYMOUTH, PROVINCE OF TARANAKI.

Plate I is a general outline of part of the Province of Taranaki, shewing, with the exception of a small block of land to the southward, called Tataraimaka, the whole of the land cleared and available for cultivation.

The general line of the dense forest is shewn, exhibiting the narrow belt along the sea shore in actual occupation by Europeans; and the small block of land on the south side of the River Waitara, near its mouth, recently acquired, and which acquisition was the immediate cause of the existing war, is also indicated.

The country is intersected by numerous small streams taking their rise in Mount Egmont, a volcanic mountain 15 miles inland; they are ordinarily fordable, but deeply cut into the general surface of the country, with steep descents into their beds, which are composed of large boulder stones of volcanic origin.

Besides these streams, there are numerous deep gullies between and nearly parallel to them, also terminating at the sea, which in heavy rains are the channels of considerable bodies of water, and at all times swampy at the bottom.

The main line of communication from the town, north and south, called the Devon Line or Road, runs generally parallel to the sea, crossing the streams and gullies nearly at right angles, so that this road is a rapid succession of rises and falls. The road is not metalled, and the soil being a light clay, mixed with sand or volcanic dust, it becomes in winter a mass of mud, in which carts and drays sink up to their axles, whilst in summer it is a fine impalpable dust. This dust being blown away by high winds causes a hollow in the centre of the road, which again becomes a bed for rain water and mud, and the operations, thus alternately repeated, render the road all but useless in winter, hence land communication is excessively difficult and at times almost impracticable.

The small stream running through the centre of the town is bridged with a wooden bridge capable of bearing heavy drays, so also is the River Henni, three-quarters of a mile to the northward. Over the River Waiwakaiho, the most considerable stream in the province except the Waitara, there is a well constructed bridge of 120 feet span.

The Rivers Mangoraka and Waiongona are not bridged and their passage is very difficult, owing to the steep descents and ascents to and from them, to the large boulders of which their beds are composed, and to the rapidity of the current, which, after the least rain, becomes almost irresistible. Between the gullies and streams on either side of the Devon Road, there are numerous elevations, some of the general form of truncated cones, others in the form of peninsulas jutting into the bends of the rivers, precipitous on three sides and gradually rising or falling on the fourth to the narrow belts of table land between the streams and gullies. These elevations are the sites of native pahs, now for the most part slightly enclosed with pales or stockading, but capable in a few hours of being made formidable and impracticable to assault without sufficient preparation; thus, if occupied by an enemy, an advance along the road must be a continued series of small sieges. Outside the European boundary the face of the country between the forest and sea is very partially cleared, the natives having merely small cultivated patches. The uncleared portions are covered with fern, in parts 5 or 6 feet high, New Zealand flax, and dwarf shrubs affording perfect cover to the savage enemy, which they well know how to make use of and to slip through with facility, but impeding the movement of a soldier to a most embarrassing and fatiguing degree.

(Signed) T. R. MOULD, Colonel,
Commanding Royal Engineer.

ROYAL ENGINEER OFFICE,
New Plymouth, 15th October, 1860.

SIR,

I have the honor to submit, for the information of the Major-General Commanding, the following Report, accompanied by a sketch of the Engineer operations, carried on for the attack of the Pahs on the north (right) bank of the Kaihihi River.

On the afternoon of the 10th instant, after the arrival of the field force at the selected site of the encampment, (which was in two portions, one on each side of a steep gulley) entrenchments were rapidly thrown up to secure the camp from annoyance by distant firing of the enemy during the night, and shortly afterwards, the reconnoissances which were made towards the right and left of the camp towards the enemy's position, enabled me to submit a general plan for the approval of the Major-General.

At 6 o'clock on the morning of the 11th instant, a working party of 250 men, with a non-commissioned officer and eight men of the Royal Engineers, left the Engineer Depôt, carrying tools and gabions, preceded by a covering party of 150 men, who advanced in extended order with the necessary supports to the ground I had selected for opening the trenches.

Having, with the assistance of Captain Pasley, Royal Engineers, whom the Major-General had obligingly placed at my disposal for duty in the trenches, traced out a line of parallel, the nearest part about 200 yards from the Orongomahangu Pah, and laid out partially under cover of a light bush, and partially on the reverse slope of a slight rise in the ground; the working parties commenced the trench at about 7 o'clock, and worked with such spirit that in about two hours they were so well covered, that I considered it advisable to send to the camp for the guns.

Strange to say, but fortunately for the working parties who would otherwise have suffered some loss, the enemy did not fire a single shot until half-past 10, by which time the guns had reached the ground and preparations were making for laying the platform for the 8-inch gun; this being completed soon after 12 o'clock, and the gun mounted, fire was opened from it, from two 24-pounder howitzers and one coehorn mortar, which threw shot and shell with great precision at intervals, with the object as well of breaching the stockade as of searching the rifle pits, the latter being, it is believed, well effected by the judicious use of small charges and good elevation in the howitzers, for the fire of the enemy, except at first, was feeble, and caused only one slight casualty on the right of the attack, the other casualties being from the fire of a body of the enemy in the bush on the left front of the parallel. A small, but scarcely practicable breach if the pah had been energetically defended, was effected by the projectiles from the 8-inch gun. The perfecting of the parallel so as to give complete cover, and the construction of some traverses, was carried on during the remainder of this day.

At 6 P.M. the day working party was relieved by 75 men, with a detail of Royal Engineers as in the morning, the whole in charge of Captain Mould, R.E., who commenced the construction of a sap from the parallel which was continued during the night, the mass of the working party still further raising and improving the parapets of the trenches.

At 6 o'clock, a.m., on the 12th, the night working party was relieved by 150 men, with the detail of Engineers as before, and were employed in rapidly pushing the sap ahead, and widening it into a trench, which it was proposed to carry on, well defiladed, to a short distance from the pah.

The enemy being quiet the whole morning, and not having fired a shot since about 11 o'clock the previous night, the Major-General determined to assault; and having had a howitzer moved to the front, and a strong force of skirmishers, consisting partly of natives, after a shell and a charge of canister was thrown into the small breach, the assaulting party moved forward and entered the pah, which was found to be evacuated by the enemy, and was destroyed.

As the second pah, Puke-kakariki, was somewhat less than 300 yards from Orongomahangu, and not a shot was fired from it during the advance upon the latter, the presumption was that it also was evacuated; as, however, the enemy might have been there in force, keeping quiet in hopes of luring on the troops, it was considered prudent to bring the two howitzers well to the front, and after three rounds fired from each, the last being canister, the troops entered the pah and destroyed it.

The latter pah was of a construction similar to others which have been previously destroyed, it was nearly square, surrounded by two rows of palisades, the outer row being covered with bundles of green flax, and having inside the usual rifle pits communicating underground with each other. (See Pl. III).

Orongomahangu was different, it was situated on the summit of the precipitous cliff forming the bank of the Kaihihi, which here makes a sharp turn, and the outer line of the pah was traced across the sort of peninsula formed by the bank (the rear of the pah being the bank) and consisted of the ordinary two rows of palisades covered with bundles of green flax, then the rifle pits well traversed, backed immediately by the high earthen bank of a pah so old that trees were growing on the summit thereof. (See Pl. III).

The accompanying sketch of the ground, with the positions of the pahs and lines of trenches, is not as perfect as I could have wished, as I had not sufficient time allowed me after the capture of the pahs and previous to the march of the force on its return to New Plymouth, to make a sufficient survey. (See Pl. II).

Looking to the small effect of the projectiles on the stockade, I am confirmed in the conclusion at which I had previously arrived, that a practicable breach cannot be formed in them by artillery, nevertheless, its use is essential for the purpose of searching the rifle pits; and in cases similar to the pah of Orongomahangu, where there is a high bank within the stockade immediately at the back of the rifle pits, shells lodging in the bank would have the effect of mines, would render the pits untenable, and the defenders would be buried in the debris.

It will be observed on looking at the positions of the pahs, with reference to the river and the bush on the left, and to the existence of the rifle pits on the farther side of the bush from Puke-Kakariki, as shown at A and B on the plan, and to the difficult country, intersected by deep swampy gulleys to the rear of these pits, that it would have been impracticable to have surrounded both pahs at once with the view of enclosing and capturing the enemy. It is also clear that it would have been an immense risk to have surrounded Puke-Kakariki, thrusting a force between the two pahs with the rifle pits at C, immediately in rear of the investing body; and as regards Orongomahangu, the precipitous bank and the difficult character of the river, the former inaccessible, and the latter unfordable to a European, though traversed by the natives, rendered an investment of it impossible.

The defenders occupied and held for a time this strong position, but eventually left it, hopeless of a successful defence or of causing much loss to the assailants who adopted a mode of attack to which they were unaccustomed.

Similar strong positions which cannot be enclosed and from which there are means of escape, inaccessible to the troops, may possibly be held for a very limited time and be evacuated before matters come to an extremity, but pahs in open country will be invariably left on the approach of a hostile force.

From the careful preparations made it was evident that a determined resistance was contemplated, and yet the natives were driven out in little more than twelve hours, and they will doubtless perceive that positions however strong are not proof against a systematic attack.

Capture of the pahs may be in all cases calculated upon with little loss, but capture of the defenders, from the experience already attained, will never be effected.

I would beg to bring to your especial notice the officers of the Royal Engineers who served under me. To Captain Pasley, who was unfortunately severely wounded on the 11th, every credit is due for the care and energy with which he carried out his instructions, and assisted me with his valuable advice; and to Captain Mould also, who, though subsequently for night duty, when he pushed forward the sap through difficult and encumbered ground, nevertheless took an active part in the day duty before, and after Captain Pasley was wounded, praise must be awarded. I cannot omit noticing a worthy, able, and zealous non-commissioned officer in the person of Sergeant Hewatt of the Royal Engineers, who, on the march, was constantly in advance of the column with a detachment of the corps actively engaged in smoothing difficulties in the road, in the way of the transport, and on the first day of the attack he volunteered his services, though not for duty during the day, and gave valuable and energetic assistance in the trenches until most severely wounded. His conduct is deserving of the highest praise.

I must be permitted to mention and to request the favourable notice of the Major General to the Field Officers on duty in the trenches, who were, to a certain degree, under my orders, viz.,—Lieutenant-Colonel Sillery, Deputy-Quartermaster-General, and Major Hitchins, who took a most active and untiring part in the operations, both in judiciously posting the guards of the trenches, and urging on the working parties.

I have, &c.,
(Signed) THOMAS R. MOULD, Colonel,
Commanding Royal Engineer.

The Deputy-Adjutant-General.

JOURNAL OF ENGINEER OPERATIONS AT THE WAITARA, BETWEEN THE 22ND OCTOBER, 1860, AND 18TH MARCH, 1861.

22nd October, 1860.—On the 22nd October, 1860, in pursuance of instructions from the Major-General Commanding, the Commanding Royal Engineer proceeded from New Plymouth to the Waitara, and took the command of the troops there.

23rd October.—On the morning of the 23rd October, marched with a party of 110 men from the camp with a quantity of rough timbers in carts, which had been previously prepared, to the ridge on which the abandoned pahs of Onuku-Kaitera and Puke-Takanere had been situated, and set out a stockade on the centre of the site of the former pah to accommodate 50 men, employing 60 men as a working party, with the remainder thrown out to cover the operation; one-half of the circuit of the stockade was completed during the day. The rough split timbers of the stockade averaged about 8 inches in diameter, were 14 feet long, and were let into the ground about 4 feet, touching each other. The whole of the men bivouacked on the ground during the night, one-half being on the site of each pah, protected by the old banks thereof, raised where necessary to give more cover.

24th October.—Proceeded with the stockade as rapidly as the very unfavorable weather and the supply of timber, which had to be brought from the low grounds over bad roads, would admit. Parties of equal number as yesterday were employed, who bivouacked on the ground during the night.

25th October.—Proceeded with the stockade which was closed in at noon. A flag-staff was erected, and an ensign hoisted at 5 p.m.; 50 men were left within the stockade as a guard. In the afternoon the whole of the banks of the Puke-Takanere pah were levelled, and the ditches filled in.

26th October.—Commenced the erection of the requisite cover for the men and stores within the stockade, filling in the interstices between the main timbers of the stockade, and also digging a ditch round. One-third of the guard were employed on the unskilled labor; artificers of the Royal Engineers and Militia on the other works. The guard was relieved at sunset.

27th October.—Took out a party of 200 men to cover a reconnoissance of Mahortahi pah, on or near which it was proposed to construct another stockade. The Onuku-Kaitera stockade, with its buildings and the surrounding ditch, were continued day by day; the detail of one-third of the guard and the artificers, as mentioned yesterday, being employed until its completion. The sketch annexed illustrates the work.

3rd November.—Proceeded with a party of 80 men and materials to construct a rough bridge over a difficult swamp on the Devon line, between the Waitara camp and Mahortaki, near the Waiongona River. The bridge was about half executed during the day; 20 men, with 6 artificers of the Royal Engineers, were employed, the remainder of the party being thrown out to cover the operation.

5th November.—Proceeded with a party of 80 men to complete the bridge commenced on the 3rd. The enemy, who must have discovered the work, had occupied a wooded knoll called Nga-puke-turna, on the farther side of the Waiongona River, and commenced skirmishing with the party covering the work, which was being executed with the detail as on the 3rd. Sent into the camp for an additional 100 men with a howitzer. Continued the bridge until its completion, then gradually retired; the party were followed by the enemy with much daring, until they were checked by shells thrown from the howitzer. Whilst the work was being proceeded with, about 400 natives from the Waihato crossed the Waitara, defiled over the ridge of Matarikoriko with colors flying, and having deposited their carts, goods and women, near Huirangi, many came down towards the left of the line of skirmishers, threatening that flank, but they did not come into action. Reported proceedings, and the arrival of additional bodies of the enemy, to the Major-General Commanding. One casualty only amongst the troops, a man of the 65th mortally wounded.

6th November.—It had been arranged that the Commanding Royal Engineer, with a party of 100 men from the Waitara, reinforced by 150 men from the town of New Plymouth, should take possession of Mahortaki this day for the purpose of erecting a stockade; but in consequence of the increase of the enemy's force referred to yesterday, the Major-General decided to bring out in person a stronger column, and Colonel Mould, Commanding Royal Engineer, was directed to lead a column of 300 men from the Waitara to form a junction with the Major-General at Mahortaki. The action at that locality was the result of the movement. The Commanding Royal Engineer was left with 300 men at the pah, which was entrenched and strengthened, and preparations were immediately made for the construction of a stockade on the Nga-puke-turna knoll, referred to on the 5th November.

7th November to 12th November.—From this date to the 12th, a party of 40 men were employed in felling and preparing timber for the stockade, clearing the bush from the intended site, and improving the defences of the pah, the working party for the stockade being covered by an advanced line of skirmishers. On the 10th, 50 men of the garrison were ordered to New Plymouth.

13th November to 16th November.—Commenced the construction of the stockade on Nga-puke-turna, which was closed in on the morning of the 16th, and on that night was occupied by a guard of 30 men. During the same period working parties were employed in clearing the great mass of timber and bush that covered the knoll, and levelling the old Maori banks that surrounded it.

17th November to 27th November.—Constructing barracks, stores, &c., within the stockade, and clearing bush round the knoll and on the banks of the Waiongona River; working parties 40 men daily, with 8 Royal Engineers, and Military Artificers. On the 25th, the enemy commenced the construction of a pah on the strong position of Matarikoriko.

28th November.—The garrison of Mahortaki was broken up, the troops returning to New Plymouth, and the Commanding Royal Engineer to the Waitara. Previous to evacuating the pah, the whole of the entrenchments were levelled. The Maori "whares," which served as shelter for a portion of the troops, were left standing. One officer and 40 men were left to garrison the stockade.

28th November to 27th December.—From the 28th November to the 27th December no operations of any kind were in progress, but in the interval, gabions, sap rollers and fascines were prepared for service.

28th December.—A strong column of troops left New Plymouth this day for the Waitara, as also the Major General, for the purpose of undertaking the reduction of the pah on Matarikoriko, referred to on the 25th November.

29th December.—A column of 900 men of all arms with four guns and howitzers, marched at $3\frac{3}{4}$ A.M., and having arrived on the site of the old Kairau pah (destroyed on the 11th September) about 1100 yards distant from Matarikoriko, a redoubt (Pl. IV. No. 1), for the accommodation of about 500 men was commenced for the purpose of serving as a depôt for the attack of the pah, and subsequently for that of the position of Huirangi. Working parties of 150 men were employed. About 9 A.M. a volley of musquetry was fired from concealed rifled pits on the brink of a deep wooded gulley, about 150 yds. from the redoubt, which for the moment interrupted its progress, but it was immediately resumed and carried on under a brisk fire from the enemy until 6 P.M., when it was completely closed in. 480 men were left as its garrison, who were on the alert the whole night, the enemy keeping up an almost unintermittent fire until four o'clock the following morning.

30th December (Sunday).—The parapets of the redoubt were this day raised and improved, banquettes formed, barbettes for guns raised, platforms for two 8-inch guns laid, and the guns mounted on the left face of the redoubt, pointing towards Matarikoriki. The enemy who, at daylight, had hoisted a white flag, indicating a desire for a truce, quietly looked on at a distance at the operations, and they were not disturbed.

31st December.—It having been presumed that the enemy had abandoned Matarikoriki, and his rifle pits in advance thereof, a clergyman, of the name of Wilson, who was especially attached to the natives, and who had arrived in the district for the purpose of negociating with them terms, in reference to the treatment of wounded soldiers, went towards the pah, and having ascertained the fact, it was immediately taken possession of, and preparations were commenced for constructing a stockade on the site. 100 men with a howitzer were posted as a garrison within the pah.

1st January to 9th January, 1861.—Working parties, about 60 in number, were engaged in the construction of a stockade on Matarikoriki, and in the destruction of the enemy's rifle pits, and in clearing the vicinity of the post from scrub and high fern.

10th January.—The Commanding Royal Engineer took out a column of 450 men to reconnoitre the country in the direction of Mataitawa, the principal location of the enemy, with the view to the establishment of other stockaded posts.

11th January to 13th January.—The stockade on Matarikoriko was proceeded with on this and the three following days. The garrison was fixed at 60 men. The stockade was similar in construction and arrangement to that on Onukukaitera, but a little larger to accommodate more men.

14th January.—Commenced the construction of a redoubt (No. 2, Pl. IV) about 500 yards on the right front of No. 1 or the Kairau redoubt, 26 yards square interiorly, which was completed in about 11 hours. The parapet was about 7 feet high, and averaged 6 feet thick. Banquettes were formed and a barbette raised for a howitzer on the right front salient angle. Working party, 60 men, with a detail of the Royal Engineers. The redoubt was garrisoned with 128 men, including artillery.

16th January.—A Sapper of the Royal Engineers who had gone out of No. 1 Redoubt to collect fire-wood, was severely wounded by the fire from a party of the enemy who were in ambush about 400 yards from the redoubt; a soldier of the 65th was at the same time mortally wounded and the body carried off by the enemy.

18th January.—A redoubt (No. 3, Pl. IV) 30 yards square interiorly, was commenced about 400 yards to the left front of No. 2, and completed in 11½ hours and was occupied at night by a garrison of 100 men, one howitzer was mounted "en barbette" at one angle of the work, and a second placed in an embrasure. Working party, 60 men, with a detail of Royal Engineers. The parapet was similar to that of No. 2. The enemy fired briskly at intervals during the day with very little effect, the casualties being only an artilleryman severely wounded in the thigh, and a volunteer slightly contused, but their fire was rendered uncertain, their attention being distracted by that from the artillery.

19th January.—A right wing to Redoubt No. 3 was commenced and nearly completed during the day, a working party of 60 men being employed. A platform for an 8-inch gun was laid on the front face of the wing, and the gun mounted. Occasional firing from the enemy.

20th January.—The right wing of the redoubt commenced yesterday, was completed this day, and a communication made between it and the centre. A left wing was also commenced and the front face completed and part of the left face. There was not any interruption from the enemy.

21st January.—The left wing of the redoubt was carried on this day nearly to completion by working parties of the same strength as on previous days.

The garrison was strengthened by 100 men, who were posted in the right wing of the redoubt. The enemy occasionally fired briskly but caused only one slight casualty.

22nd January.—The left wing of the redoubt was completed this day and an additional garrison placed in it, including the head-quarters of the 40th Regiment. A double sap or gabionnade, directed towards the centre of the enemy's position, was commenced in the afternoon, and nearly 200 feet were executed in the course of the day, the first 150 feet without traverses. Working party, 50 men with 5 Royal Engineers.

The foregoing are extracts from the private Journal of the Commanding Royal Engineer, the details of the subsequent operations are principally from the Journal of Captain Mould, the senior executive Engineer. Sketches of the Redoubts (see Pl. IV) are annexed with a section, and it is necessary to explain that the soil was of such a nature—a sandy clay—that the sides of excavations would stand if cut vertical. The parapets of the redoubts were made with earth and fern in layers, which admitted of their being erected perpendicularly.

23rd January.—At 3¾ A.M., the enemy attacked the left face of No. 3 Redoubt with great resolution. About 30 are supposed to have crept into the ditch unseen, and upwards of 100 more were near at hand in the fern as an assaulting party, with large supports to their rear at the head of a gulley, and there were also assailants on the right flank. When discovered, a heavy fusilade was commenced by the natives, who made desperate attempts to scale the parapets, and were only finally checked by the arrival of troops from No. 1 Redoubt, and throwing shells into the ditch, on the suggestion of Lieutenant Warburton, R.E. One Sapper of the Royal Engineers was shot dead whilst turning out of his tent. The sap was continued at 8 A.M. as yesterday, but traverses were placed alternately on each side at distances of from 10 to 12 yards. Total length executed up to 8 P.M., 53 yards; 5 Engineers and 40 men of the Line being employed.

24th January.—The sap continued as yesterday, commencing at 5 A.M. and working until 8 P.M., 54 yards being executed with a party of 5 Engineers and 35 of the Line, who were relieved every four hours. At 8 A.M., a return or demi-parallel was commenced on the left of the sap, about 150 yards from the commencement, and a length of 30 yards executed with a detail of 2 Engineers and 15 of the Line, according to the Section, Pl. IV, Fig. 8. The section of the sap as executed up to the end of this day was as shewn in Pl. IV, Fig. 9.

25th January.—Sap continued at 5 A.M., but the section was increased in width as shewn in Pl. IV, Fig. 10. Continued the work until 8 P.M., the length executed being 56 yards, with a detail of workmen as yesterday. The demi-parallel was carried about 12 yards farther with an epaulment, 2 Engineers and 20 men being employed. A party of 20 men were also employed at the rear of the sap, taking down the gabions for use in front and making up the parapets with fern, the section of the first three days' work being increased to that last shewn above. In addition to the length of sap mentioned above, a farther length of 10 yards was carried on with fern, making a total length of 66 yards.

26th January.—Sap continued as yesterday, 6 Engineers and 40 men being employed, executing 66 yards between 5 A.M. and 8 P.M. 20 men were also employed in taking down gabions and reforming the parapets in the rear. The

Commanding Royal Engineer and the Deputy Adjutant General made a reconnoissance to the left of the sap skirting the great gulley, and advanced to some of the enemy's rifle pits occupied by them on the 18th inst., Lieut. Battiscombe, Royal Navy, Assistant Engineer on duty in the sap.

27th January.—Sap continued as yesterday with a detail of 4 Engineers and 30 Line, working from 5 A.M. till 7 P.M., 49 yards being executed. A square redoubt, 13½ yards a side interiorly, was commenced at 5 A.M., on the right side of the sap, and carried on until 7 P.M., when it was nearly completed; 100 men were employed on this work from 5 A.M. until noon, and 70 men from noon until 7 P.M. The front of the redoubt, which was numbered 4, was 310 yards from the commencement of the sap. It was garrisoned by 50 men; Lieutenant Warburton, R.E , on duty.

28th January.—60 yards of the sap executed this day, between 5 A.M. and 7 P.M., with a party of 3 Engineers and 5 men of the Line; 2 Engineers and 25 men employed in taking down gabions, and reforming the parapets of the sap with fern, and 20 men in completing the banquette of No. 4 Redoubt, clearing out the ditch, the earth being thrown up to form a slight glacis, and planting palisades in the ditch.

29th January.—Captain Mould, R.E., on duty. The sap was continued as before by a party of 5 Engineers and 40 Line, and 62 yards executed. 30 men were also employed in reforming the sap to the rear, and passing the gabions to the front, and 3 Engineers and 20 men in making gabions. Work from 5 A.M. to 7 P.M. The gabions were generally made at the Waitara Camp, principally by the Naval Brigade, assisted by men of the Line, under the direction of non-commissioned officers of Royal Engineers.

30th January.—5 Engineers and 40 men employed on the sap from 5 A.M. until 7 P.M.; 71 yards executed, 2 Engineers and 30 men reforming sap with fern. At 3 P.M., a redoubt (No. 5), to be 24 yards square interiorly, was commenced on the left side of the sap, about 530 yards from the commencement of the sap, and 260 yards from the nearest of the enemy's rifle pits. A screen, consisting of a double row of filled gabions with an empty row on the top, was previously placed in front of the front face of the redoubt. 3 Engineers and 30 men employed on this work.

31st January.—Sap continued as before; working party, who were employed from 5 A.M. until 8 P.M., 3 Engineers and 30 of the Line. Redoubt No. 5 was completed by 8 P.M., with banquettes complete, and a "barbette" for a 24-pounder howitzer on the left front angle, an average party of 8 Engineers and 100 men being employed. The enemy fired a little at different periods of the day.

1st February.—100 men garrisoned the redoubt. 110 yards of the sap executed between 5 A.M. and 7 P.M., with a party of 5 Engineers and 50 men of the Line. 3 Engineers and 30 men were employed in taking down gabions in the rear, and reforming parapets; 2 Engineers and 20 men employed in clearing the ditch of No. 5 Redoubt from 5 to 8 A.M., and 2 Engineers and 20 men from noon until 7 P.M. in making gabions. In the afternoon as the enemy appeared to have abandoned the Huirangi position, their rifle pits were entered as a reconnoissance.

2nd February.—Sap continued by 6 Engineers and 50 men, from 5 A.M. till 3 P.M., in which time 95 yards were executed, crossing the enemy's line of rifle pits, and passing beyond them about 20 yards. Total length of double sap executed 768 yards. A single sap, traversed, was carried on in continuation, commencing at 3 P.M., with the above party, and 50 yards were executed by 7 P.M.; 3 Engineers and 30 men were employed in reforming the parapets of the sap in the rear, and 2 Engineers and 20 men in making gabions. At 3 P.M. a redoubt (No. 6, Pl. IV) was commenced, its front slightly in advance of the enemy's rifle pits, in the midst of a field of high Scotch thistle; and to the left of the Huirangi road its left front angle resting on a patch of close bush, extending away to the left and front.

3rd February.—The single sap was continued as yesterday afternoon, from 5 A.M. until 1½ P.M., when it was stopped, a party of 2 Engineers and 15 men executing 40 yards in that time. The redoubt commenced yesterday was carried on throughout the day, from 5 A.M. till 7 P.M., 120 men in all being employed in the work. A party of 25 selected axe-men, principally from the 65th Regiment, were employed in cutting down the bush on the left of the redoubt. The Commanding Royal Engineer examined and reconnoitered the bush on three sides thereof.

4th February.—11 Engineers and 120 men employed in completing No. 6 Redoubt, which was garrisoned by the 65th Regiment, including its head quarters. 25 axe-men employed as yesterday in cutting down the bush. A platform for an 8-inch gun was laid in the right half bastion of the redoubt.

5th February.—A party of 80 men employed in forming banquettes in the redoubt, widening, deepening, and clearing the ditch, and partly raising the parapets, 25 axe-men employed as before; 12 Engineers superintending the several works.

6th February.—A party of 30 men employed in filling in rifle pits in the bush and about 400 yards to the left, near the great gulley, 25 axe-men cutting down the bush.

7th February.—The 25 axe-men employed as before and a party of 50 men in filling in the enemy's rifle pits (to the right of No. 6 Redoubt), which extended over a space of nearly half a mile.

8th February.—An axe party of 40 men were employed in clearing the bush.

9th February.—The axe party of 40 men employed as yesterday, and in the afternoon, 4 Engineers and 25 men were employed in making a small foot-bridge and road over a gulley to the left front of No. 6 Redoubt.

10th February.—Commenced the construction of a redoubt (No. 7, Pl. IV) about 1,300 yards from No. 6, and about 800 yards from Te-ari Pah (Pukerangiora), about 8 A.M., employing 24 Engineers and 130 men of the Line, under cover of a line of skirmishers, supported by 4 guns and howitzers. The enemy opened fire from a line of rifle pits, in commanding positions, and from the pah, about 7 A.M., and fired briskly throughout the day, under which the work of the redoubt was carried on, and so far completed as to be occupied by a garrison at night. The garrison was 400 men, including the head quarters of the 40th Regiment. The excellent and gallant Captain Strange, of the 65th Regiment, was mortally wounded in the early part of the day.

11th February.—The works at the redoubt were continued; the parapets being raised, and ditches deepened, and the front face, and part of the left face, surmounted with filled gabions, with sandbag loop-holes at intervals, to protect the interior from the plunging fire of the enemy, which was sharply kept up, killing one man, and wounding an officer and one man within the redoubt; 9 Engineers employed superintending the working parties.

12th February.—The works of the redoubt were completed this day, 9 Engineers being employed in superintending and assisting the garrison. A party from No. 6 Redoubt were employed in destroying cultivations of the enemy on the banks of the Waitara River to the left rear of No. 7 Redoubt. 9 Engineers were employed in erecting a screen for an 8-inch gun on the left flank of the redoubt, it was 12 yards in length, and was formed of two rows of gabions surmounted by a third row all filled and backed up with earth from a ditch in the front. The enemy fired briskly all day, especially at a party taken out to reconnoitre the enemy's position and the ground in front.

13th February.—The day being very inclement with high wind and heavy rain, the only work done was to lay the platform for an 8-inch gun in the position prepared for it yesterday.

14th February.—5 Engineers and 30 men were employed in constructing a sufficient bridge for carriages over the gulley bridged for foot traffic, on the 9th inst., at the same place 45 axe-men engaged in cutting down the Karaka trees in a grove between Nos. 6 and 7 Redoubts. 9 Engineers and 80 men of the Line employed in making an addition to the left of No. 7 Redoubt, to give more accommodation.

15th February.—9 Engineers and 80 men employed in completing the addition to No. 7 Redoubt, in draining the redoubt and opening a communication between the original and added portion. A parapet was also thrown up on the right of the redoubt outside as a cover for field guns, and a party of 25 men completed the bridge and road commenced yesterday.

16th February.—A single sap of nearly the same section as given in Pl. IV, Fig. 8, omitting the reverse slope, was commenced from the right front angle of No. 7 Redoubt at 6 A.M., being directed clear of the enemy's rifle pits, where the ground dips on their right precipitately into the valley of the Waitara. 15 men of the Engineers and Line were employed, who executed during the day 51 yards, though much impeded by heavy rain. 12 axe-men engaged in cutting down the peach grove to the right front of No. 6 Redoubt.

17th February.—The sap was continued as yesterday, 31 yards being executed in four hours, during which time only, were the men able to work, owing to rain; 7 Engineers and 30 men of the Line employed. The first 62 yards of the sap were without traverses, the last 20 yards of the work this day was traversed at intervals of from 10 to 12 yards.

18th February.—5 Engineers and 15 men employed on the sap from 6 A.M. to 6 P.M., executing 60 yards with traverses complete. 2 Engineers and 20 Line were also employed in still farther raising the parapets of No. 7 Redoubt, and crowning them with sandbag loop-holes.

19th.—Sap continued as before with a party of 6 Engineers and 30 Line, who executed 50 yards between 10 A.M. and 6 P.M. 2 Engineers and 30 Line employed in raising the parapets of the redoubt.

20th February.—Sap carried on from 6 till 8 A.M. by 4 Engineers and 15 Line; 14 yards executed. Sharp firing from one of the positions of the enemy, abreast of which the sap had approached.

21st February.—52 yards executed by a working party of 5 Engineers and 15 Line, between 6 A.M. and 6 P.M. 2 Engineers and 25 Line employed in raising the parapets of No. 7 Redoubt, and widening the ditch to 9 feet, the earth being laid to form a glacis.

22nd February.—Sap continued and 54 yards executed, between 6 A.M. and 6 P.M. Working party, 5 Engineers and 15 Line. A party of the same strength as yesterday continuing the widening of the ditches of the redoubt. Some of the enemy's advanced rifle pits, from which there was some heavy firing on the morning of yesterday, were this day occupied by a portion of the guards of the trenches.

23rd February.—Sap continued as yesterday: 5 Engineers and 15 Line employed executing 70 yards in 12 hours. 2 Engineers and 25 of the Line employed as before in widening the ditches of the redoubt. The enemy in the front making very good practice on the head of the sap.

24th February.—During the last night the enemy constructed additional rifle pits on the nearer side of the crest of a hill called by the troops the "burnt hill," apparently to annoy the men working in the sap, which was now abreast of the hill, and about 500 yards from it. The sap was carried on as usual from 6 A.M. to 6 P.M., by 5 Engineers and 20 of the Line, and 50 yards were executed; the widening of the ditches of the redoubt was carried on by a similar detail as yesterday.

25th February.—The enemy in the night had made further additions to their rifle pits on the "burnt hill." The sap was carried on as hitherto, single or rather half-double sap, from 6 A.M. till 10 A.M., when 20 yards having been executed, the direction was changed towards the left of the Te-arei Pah, and was carried on as a double sap, 20 yards being executed. The working party throughout the day was 5 Engineers and 20 of the Line. The total length of single sap executed was 452 yards. The widening of the ditches of the redoubt was continued by a party of 2 Engineers and 25 Line, the enemy fired very sharply and close from the pits in the front.

26th February.—The double sap was continued and 25 yards executed during the day, making in all 45 yards. A sort of demi-parallel was also commenced on the left of the sap, about 40 yards from the commencement of the double sap, and about 20 yards of it completed, the section being similar to that executed on the 24th January. Working party, 7 Engineers and 25 of the Line.

27th February.—During the last night the enemy sallied from the pah and destroyed the whole of the double sap and the portion of demi-parallel, and more or less injured nearly 150 yards in length of the single sap. The gabions of the single sap were overturned into the trench, some of those from the double sap were removed into the pah, and the others burnt in the sap. The sap rollers were also rolled into the pah. The first intimation of the movement was the lighting of the fire which burnt the gabions. 7 Engineers and 25 of the Line were employed in repairing the damages of the single sap.

28th February.—To protect the further progress of the sap, a redoubt (square) to be of 16 yards interior side was commenced at 5 A.M., the front face thereof being 34 yards from the end of the single sap. A screen of gabions filled with earth was thrown up to cover the workmen, who were in number 7 Engineers and 80 of the Line. The Redoubt (No. 8) was completed by 7 P.M., and occupied by a guard of 50 men. The upper row of gabions of the screen was taken down and the lower double row backed up with earth to form a glacis.*

1st March.—In the morning, the whole of the old double sap was filled in and the single sap was connected with the ditch of the rear face of No. 8 Redoubt; these works were completed between 6 A.M. and 11 A.M., at which latter hour a double sap was commenced from the centre of the front ditch of the redoubt, being directed to the right (our left) of the entrance to the pah, traverses being placed at intervals of 10 yards, the length of sap executed up to 6 P.M. was 22 yards. Working party throughout the day, 7 Engineers and 40 Line. The ground was falling to the front. The enemy had put up the gabions taken from the sap on the night of the 26th ultimo, as a screen in front of the entrance of Te-arei Pah.

2nd March.—The double sap was continued at 6 A.M., and carried on until 6 P.M., 40 yards being executed with a party of 7 Engineers and 30 of the Line, the ground still falling to the front.

3rd March.—The sap was carried on from 6 A.M. till 4 P.M., on ground still falling to the front, by a party of 5 Engineers and 30 Line, 28 yards being executed. A party of 2 Engineers and 20 men of the Line were employed in widening the ditch of the left face of the redoubt to 9 feet, and making a ramp down into it from the rear, to admit of guns being taken to the front of the redoubt. An approach was also commenced from the left front angle of the redoubt, but after being carried on for about 14 yards it was stopped, being nearly enfiladed from rifle pits on the right of the pah; the sap was suspended also from being plunged into by the fire from the pah, which severely wounded the only Engineer who had been hit in the sap; and a demi-parallel was thrown out to the left, about 49 yards in front of the redoubt, and continued to the edge of a precipice, being in length 43 yards, the last 20 of which were converted from a line of the enemy's rifle pits.

4th March.—Sap continued as before from 6 A.M. till 6 P.M., with a party of 5 Engineers and 20 Line, and 22 yards were executed. Being much commanded and the ground still falling to the front, the trench was made 4 feet 6 inches deep; the traverses were placed from 8 to 10 yards apart, and made 2 gabions in height. The demi-parallel constructed yesterday was connected by an approach, working from front to rear, with the portion of approach made yesterday, and about 10 yards of the demi-parallel was made into a battery for howitzers and a mortar; working party 2 Engineers and 20 Line.

5th March.—The sap continued as usual with a party of 7 Royal Engineers and 20 of the Line, working from 6 A.M. until 5 P.M., when the progress was interrupted by a sortie from the enemy who crept through the scrub on the precipice to the left, and fired a volley into the sap, killing one man and wounding 4 others before they were driven off. To draw attention from the intended point of attack, the enemy commenced a brisk fire from the bush on the right rear of No. 7 Redoubt, and took it up along the whole line of their position. 32 yards of sap were executed.

6th March.—The ground was now rising in carrying on the sap, therefore the traverses were placed 14 yards apart, and made one gabion in height, and the trench was excavated to the depth of 3 feet only. Work commenced at 6 A.M., but was suspended at 3 P.M. on account of the heavy rain, 15 yards executed by 5 Engineers and 15 men of the Line.

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* This is shewn in dotted lines in Pl. IV, Fig. 5.—Ed.

7th and 8th March.—No work done on account of the heavy rain.

9th March.—Sap continued at 6 A.M. and carried on until 6 P.M. with a party of 7 Engineers and 20 of the Line; 47 yards executed. The enemy busily engaged in digging rifle pits to their left of their position, presumed to command the road to Mataitawa.

10th March.—The ground becoming level again and the pah commanding the sap, the traverses were placed only 11 yards apart, and were made two gabions in height. 48 yards were executed by the working party of 7 Engineers and 25 of the Line, between 6 A.M. and 6 P.M.

11th March.—Sap continued as before, but the ground being again on the rise, the traverses were made one gabion in height and placed 12 yards apart. Working party employed from 6 A.M. to 6 P.M. 7 Engineers and 25 of the Line; length executed, 35 yards.

12th, 13th, and 14th March.—Cessation of hostilities and work granted at the desire of William Thompson, an influential chief just arrived from Waikato.

15th March.—The truce having expired, the works were recommenced about 11 A.M., and a demi-parallel was commenced on the left of the sap (see Pl. IV, Fig. 11) at about 236 yards from No. 8 Redoubt, its object being to drive the enemy from their rifle pits along the edge of the precipice in advance of and to our left of the pah; 23 yards were executed by a party of 4 Engineers and 8 of the Line. An addition to No. 7 Redoubt, to contain the artillery, was commenced on the left by a party of 16 Engineers and 80 men of the Line. Two platforms for 10-inch mortars were also laid on the right of the redoubt, and the breastwork thrown up on the 15th February was continued to the ditch of the redoubt so as to give cover for four mortars—two 10-inch and two 8-inch. The enemy did not open fire until 3 P.M., when it was commenced very sharply from the whole length of their position.

16th March.—The demi-parallel commenced yesterday, of much the same section as before, was continued, and a length of 23 yards executed. Working party, 4 Engineers and 8 Line. The addition to the redoubt, which was 30 yards by 25 yards interiorly, was carried on and completed, with the exception of portions of the banquettes, and a "barbette," 21 feet by 24 feet, was constructed for two Armstrong guns. A small breastwork was also thrown up to the right rear of the mortars for an 8-inch gun, and the platform for it laid. Working party, 16 Engineers and 80 men of the Line. During the previous night the enemy made an attempt to carry off the sap roller at the end of the demi-parallel, but they were prevented by the explosion of an 8-inch shell which had been placed behind it, and connected with it and a friction tube by a line.

17th March.—The demi-parallel was continued and carried to the verge of the precipice into the enemy's rifle pits. On reaching the pits it was found that all up to a bend in the line were evacuated, and at that bend a palisade had been erected to prevent further passage along the line. Length of sap executed, 21 yards. Working party, 4 Engineers and 8 Line. A coehorn mortar was placed at the extreme end of the demi-parallel, whilst laying which Lieutenant Macnaghten, Royal Artillery, was killed. A party of 36 men was employed in completing the banquettes, &c., of the new portion of No. 7 Redoubt.

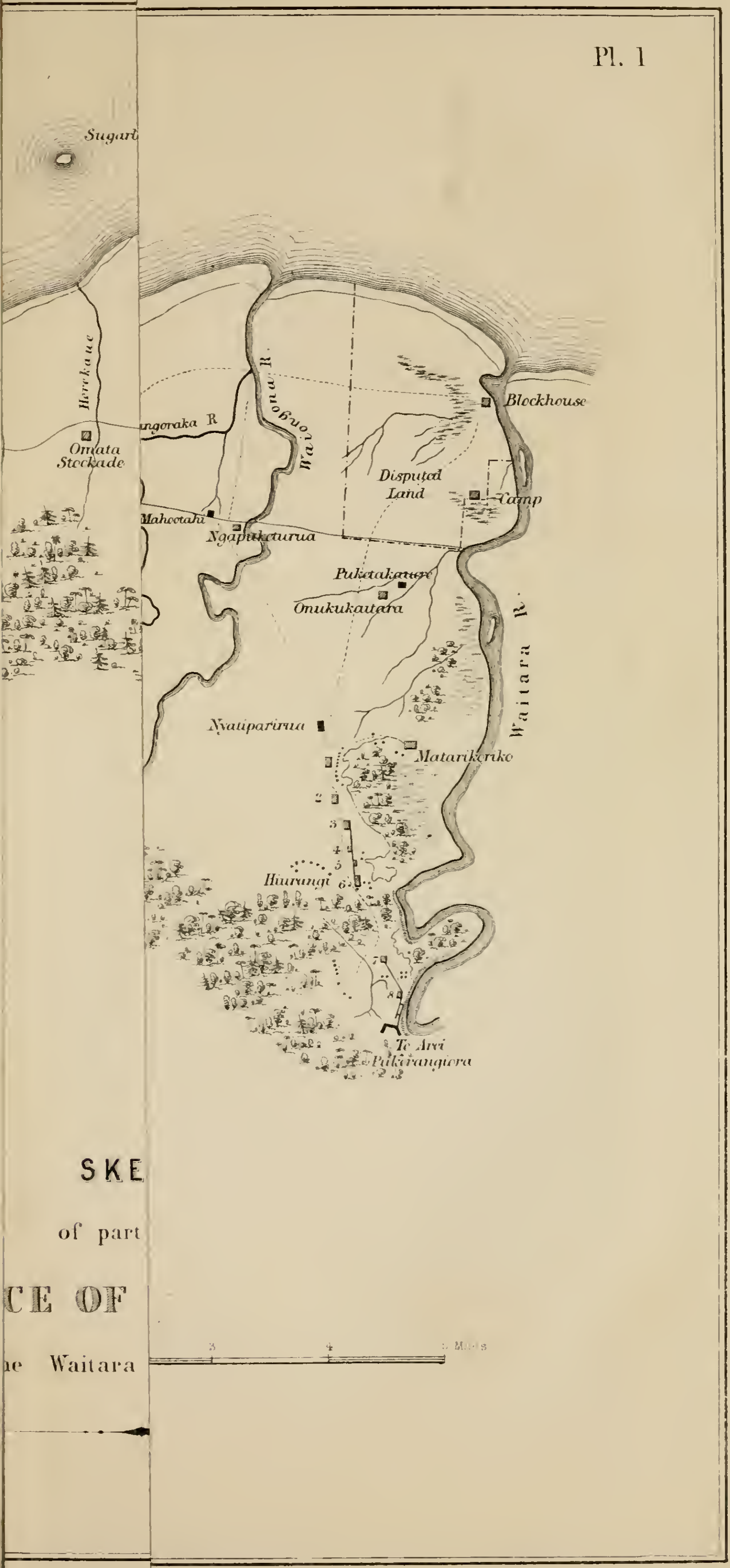
18th March.—The sap which had been suspended since the 11th inst., was recommenced at 6 A.M. this morning, by a working party of 7 Engineers and 12 of the Line, and 27 yards were executed during the day. The parapet between the old and added portions of No. 7 Redoubt was broken down, the ditch filled in, and the "barbette" made up to 36 feet in width.

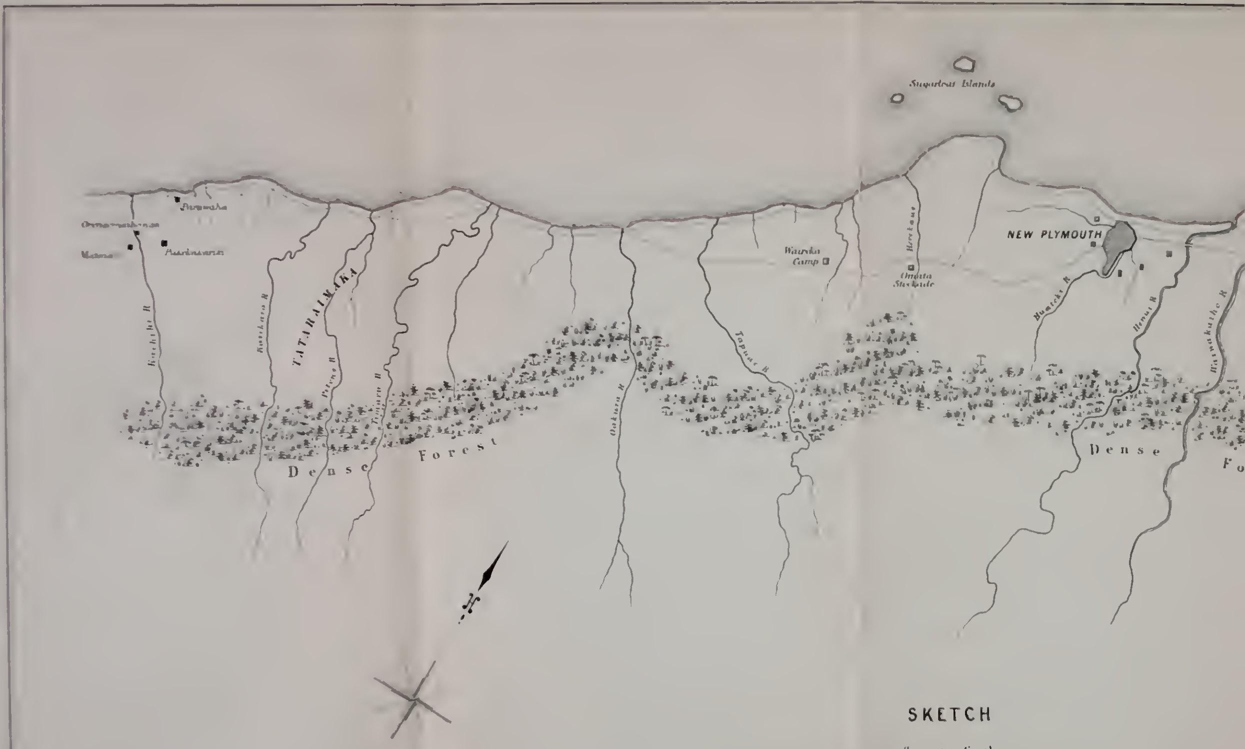
19th March.—The working and covering parties went as usual to work at 6 A.M., but the enemy having hoisted a white flag, the parties were withdrawn, and a cessation of hostilities took place to admit of conferences between the officers of the Native Department and the natives.

20th March.—A great number of the Waikato natives crossed the Waitara early this morning on their way northward to their own district. Thus virtually terminates the war in this portion of Taranaki.

(Signed) THOMAS R. MOULD, Colonel,
Commanding Royal Engineer,
4th November, 1861.

Pl. 1


Sugarl
Herekaue
ngoraka R
Omata
Stockade
Mahootahi
Ngapukeurua
Waiongona R.
Disputed
Land
Blockhouse
Camp
Puketakauere
Onukukaitara
Waitara R.
Nyatipariruia
Matarikoriko
1
2
3
4
5
6
7
8
Huirangi
Te Arei
Pukerangiora
SKE
of part
CE OF
he Waitara
3
4
5 Miles

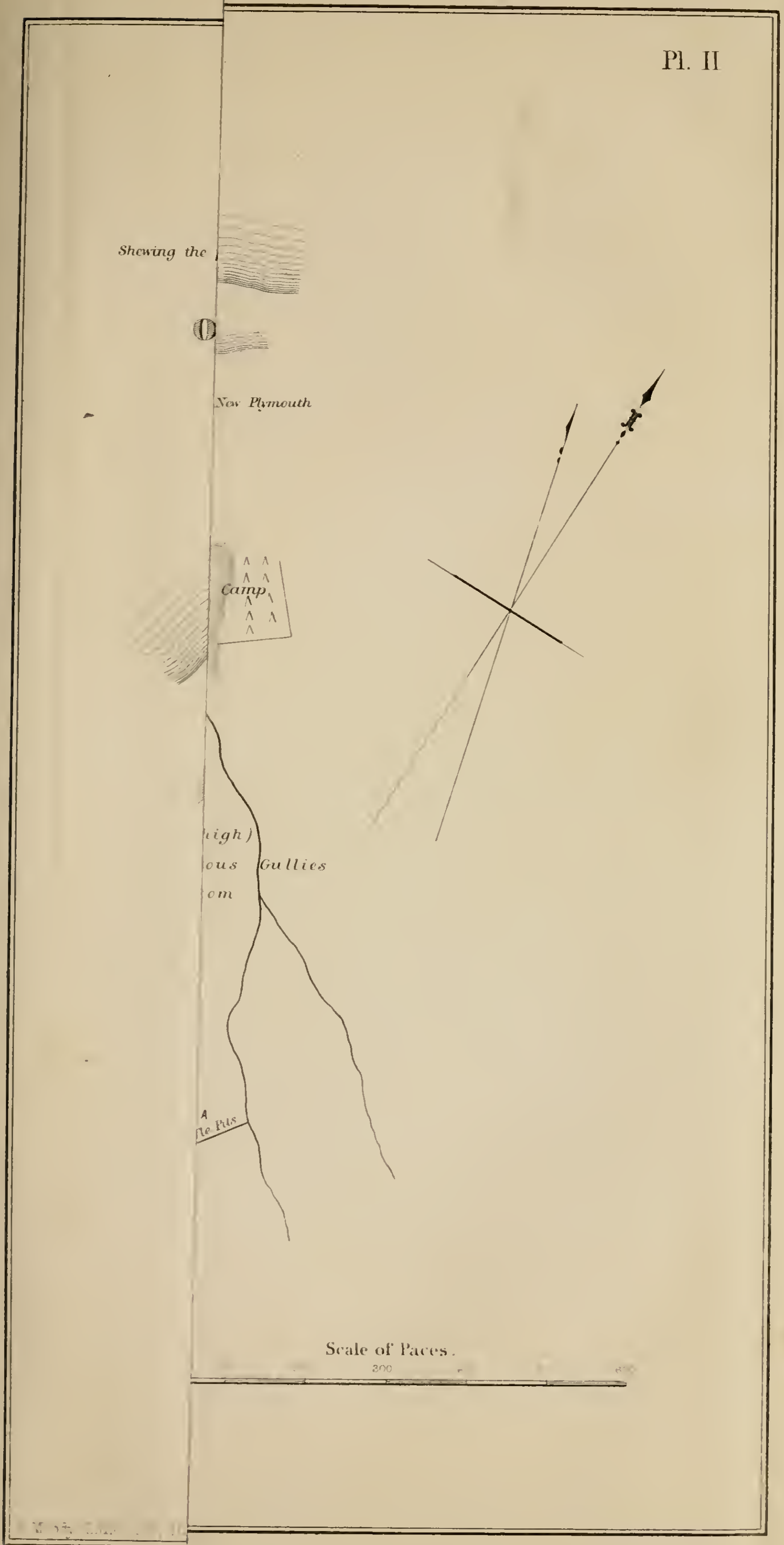


SKETCH

of part of the

PROVINCE OF TARANAKI, N.Z.

Pl. II


Shewing the
New Plymouth
Camp
high)
ous
Gullies
om
A
le Pits
Scale of Paces.
300
600

SKETCH

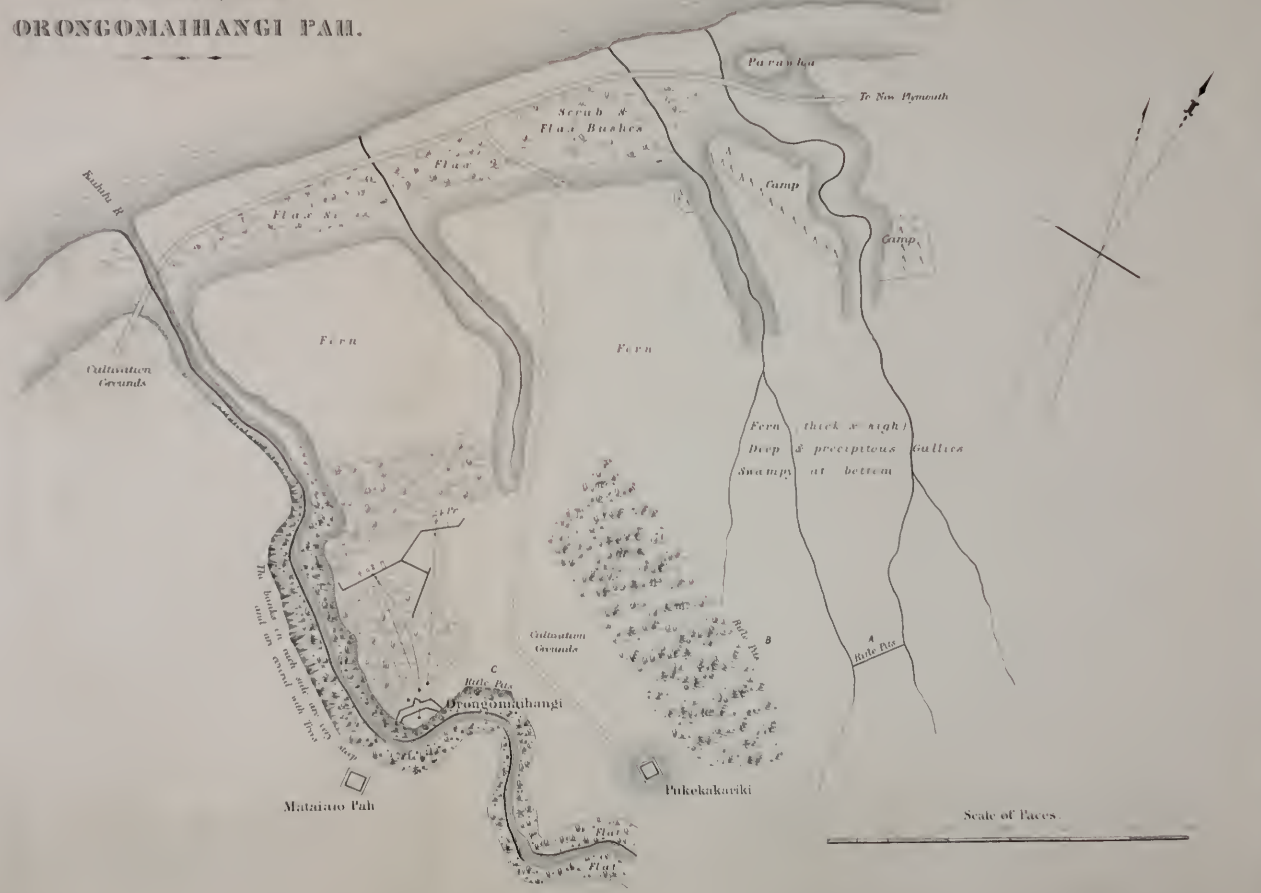
of the Ground near the

KAIHIHI RIVER,

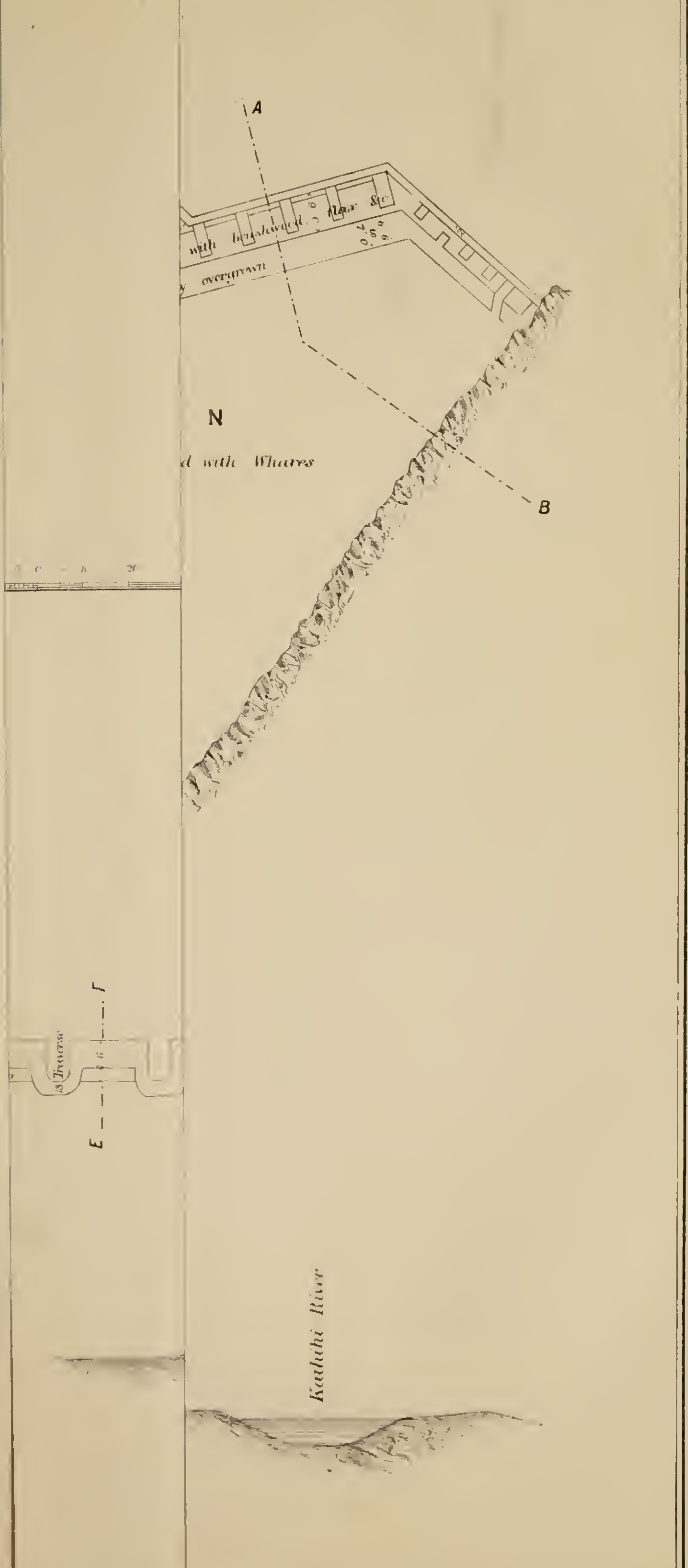
Showing the positions of the Rebel Pahs attacked on the 11th & 12th October 1860

also the Parallel & approaches to

ORONGOMAIHANGI PAH.



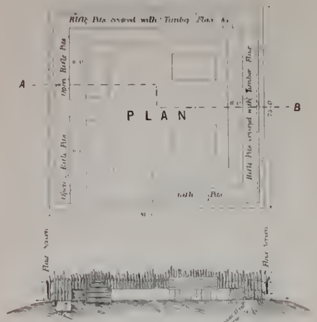
Pl. III.



C Moody, Litho 257, High Holborn

Sketch of Pukekakariki Pah

Destroyed on the 12th October 1860



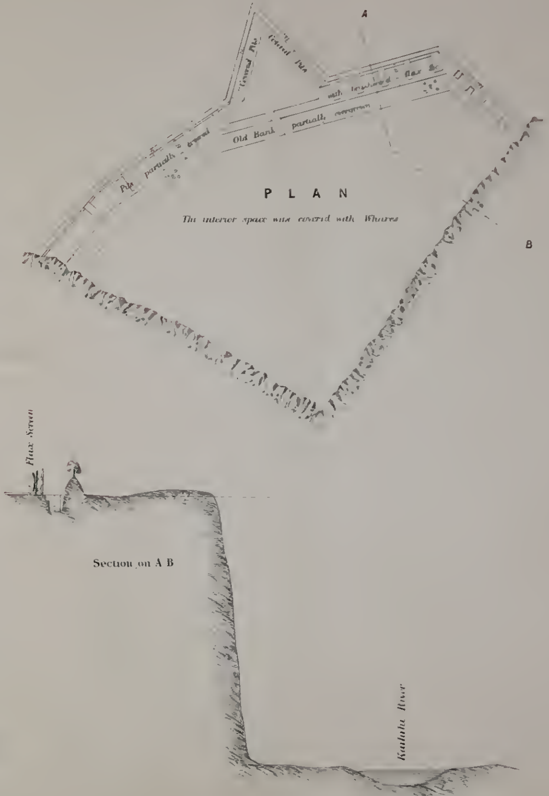
Section on A B

SCALE

10 Feet to an Inch

Sketch of Orongomaihanga Pah

Captured on the 12 October, 1860



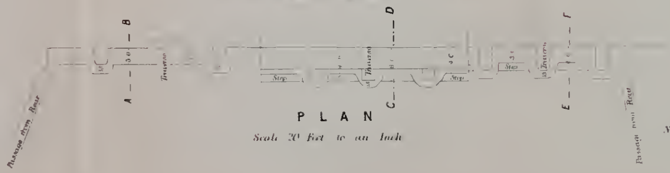
The interior space was covered with Whares

Section on A B

SKETCH

Explanatory of the Constructions of

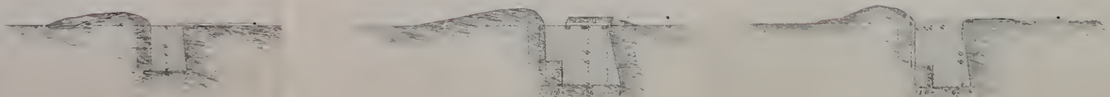
MAORI RIFLE PITS.



PLAN

Scale 20 Feet to an Inch

N. B. The interior of the covered Pits was lined with Fern &c and used as sleeping places. Food was also cooked in them



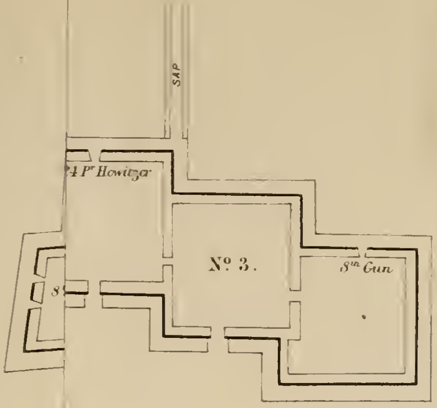
Section on A B

Section on C D

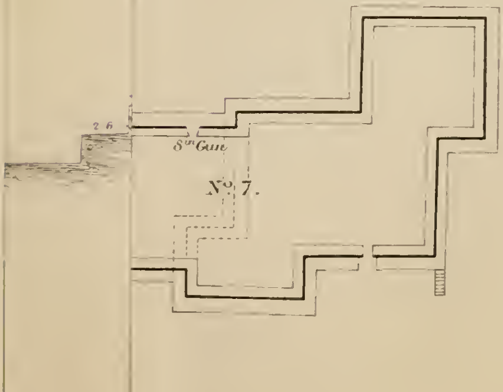
Section on E F

Scale for Sections, 10 Feet to an Inch

Pl. IV.



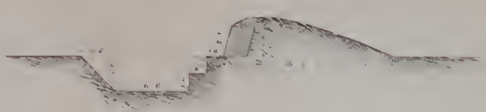
e face of Nº 3 Redoubt attacked by
e enemy on the morning of the
rd January, 1861.
4 and 5 Redoubts were simple square
edoubts.



C Moody, Litho 257, High Holborn

Pl. IV

Fig. 8



Scale for Figs 8 9 & 10
10 ft - 1 in

Fig. 9

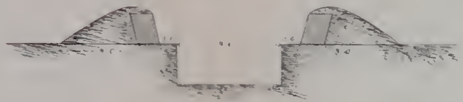


Fig. 10.

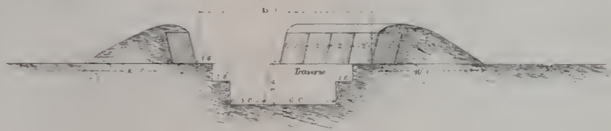
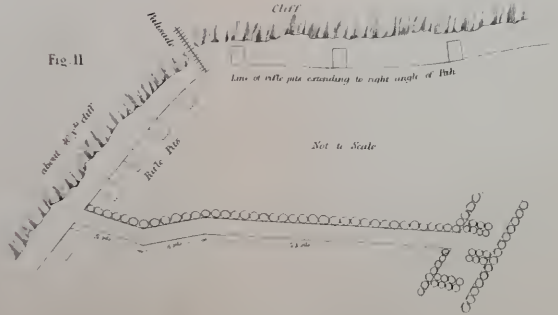
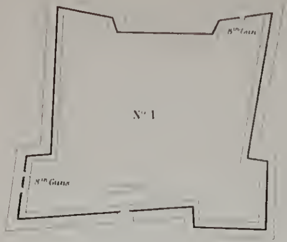
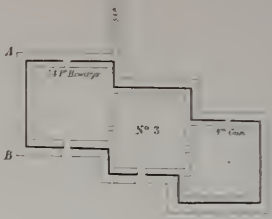


Fig. 11



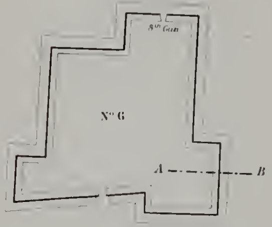


SKETCHES OF
REDOUBTS
ON THE
KAIRAU PLAINS.



A B The face of No. 3 Redoubt attacked by the enemy on the morning of the 23rd January, 1861

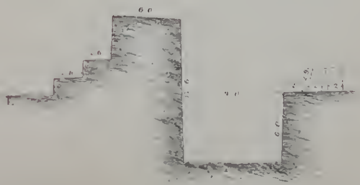
Nos. 2 4 and 5 Redoubts were simple square Redoubts



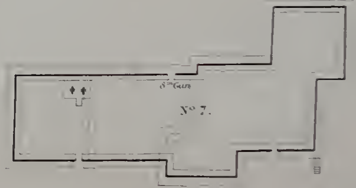
Scale
for Section, 10 Feet to an Inch.

Scale for Plan. 40 Yards to an Inch

Fig. 5



Section on A B



PAPER V.

MILITARY TELEGRAPHS.

By CAPTAIN SCHAW, R.E.

In military operations, time is most frequently all important, and some means of communicating orders and intelligence rapidly between distant points has, therefore, always been a desideratum. The simplest form of telegraph, and one which has been used in most uncivilized countries, consists of signal fires, visible at night, or clouds of smoke as day signals, made on the tops of hills at convenient intervals, and by means of which some communication, agreed on before hand, can be rapidly transmitted from point to point. Amongst the Greeks and Romans several systems of telegraphy, more or less complete, were in use. The most perfect appears to have been that described by Polybius, in his history of the Punic wars. The letters of the Greek alphabet were classified by fives. At each signal station two screens were erected; behind each screen were concealed five torches or other signals. The torches on the left hand denoted the class, and the torches on the right the particular letter of the class. Thus, one torch exhibited on the left and three on the right would signify the third letter of the first class, or gamma.

In more modern times a great variety of semaphores have been used; none, perhaps, so perfect as the Chappé telegraph, invented by the brothers Chappé in France, and adopted by the French government in 1794. This consisted of an upright post or frame, bearing a cross piece, moveable on a central axis, and which had at each extremity a smaller moveable wing with a counterpoise. The larger bar was called the regulator, and the two wings indicators. With this machine 196 different signals could be made; and in clear weather, with well trained operators, three signals in a minute could be transmitted along a line of telegraph, comprising only a few stations; but, in a long line, the rate was considerably slower. In telegraphing from Toulon to Paris, a distance of 475 miles, and having 120 telegraph stations, a signal took 10 or 12 minutes to pass from one extremity to the other, and not more than one signal in a minute could be sent. These may probably be taken as the maximum rates of signalling which have practically been attained with visual telegraphs.

A semaphore of a different description has been in use in the English service until very lately. It consisted of a mast with a yard, to which could be hoisted, at pleasure, a number of large balls made of wicker work, or frames covered with canvas, and which served to denote numbers corresponding with words in a telegraphic dictionary. Semaphores, such as these, were used in the Peninsular war to communicate between the forts on the lines of Torres Vedras. Sir Charles Pasley had a portable field telegraph constructed, somewhat on the principle of the Chappé telegraph; simpler, but less perfect. Two of these telegraphs are in the Model Room of the Royal Engineer Establishment, at Chatham; they have two moveable arms, and a fixed arm serving as an index: 27 distinct signals could be made by means of this telegraph, but it was never practically used, as far as I can learn. In our navy, flags have been hitherto in use for signalling, and have answered the purpose moderately well. In all these systems of visual telegraphs, however, it will be evident that the signals could not be seen well, except when viewed in one direction. For naval service especially, this is objectionable, because the direction of the wind governs the direction in which the flags are readily to be distinguished, and vessels being constantly in motion, none of the semaphore or flag signals, which can only be viewed distinctly in one direction, are satisfactory modes of communicating with a number of vessels in different positions. The French, indeed, in their military telegraph, which is very similar to Sir Charles Pasley's, have the apparatus so arranged that it can be turned on a vertical axis, and the signals exhibited in any required direction; but this arrangement only partially meets the objection above mentioned.

A new system of visual telegraph has now been adopted into the British service, being a modification of a system proposed by Mr. Redl, in which four collapsible cones, suspended vertically above one another, are the signals used. These cones, from their form and position, are evidently well adapted for the purpose, presenting a similar appearance from whatever direction they may be viewed. It is believed that the late General Blanshard, R.E., was the first to propose the cone as the best form for a visual telegraph signal, although his system was never perfected. Fifteen combinations and permutations can be made with the Redl cones, which are used to express the 10 numerals and 5 other auxiliary signs. The cones are intended to be used in connection with a code of signals which has been drawn up under the direction of the Ordnance Select Committee, by Captain Ross, 5th Regiment, and Lieutenant Colomb, R.N., and which contains 8,241 words or sentences, corresponding with numbers attached to them. This falls very far short of the number of articles in Sir Home Popham's Naval Signal Dictionary, which contains 13,000 words and sentences; and Sir Charles Pasley, in a careful *resumé* of the subject, published in the last edition of the "Aide Memoire" gave it as his opinion that a perfect dictionary of the sort ought to contain about 30,000 words and sentences. It is, however, possible to spell words by means of the cones, which may make up for the deficiency of the dictionary, and it appears best that the minimum number of words and sentences generally in use should be given in such a dictionary, in order to facilitate reference as much as possible.

In the visual systems of telegraphy one point is worthy of remark; where there are many intermediate stations, and intelligence is to be communicated only between the terminal stations, rapidity is gained in proportion to the diminution of the number of changes of signal, because the greater the *variety* of signals which the telegraph is capable of forming, the more quickly will the higher numbers be expressed. With the Chappé telegraph, for instance, any number up to 196 was expressed by some one position of the telegraph arms; and any number above that, up to 19,699, by two positions. In the cone telegraph, each figure requires a separate signal, and the transmissions would be proportionally slow. On the other hand, however, the vast variety of the positions capable of being assumed by the arms of the Chappé telegraph, must have made it impossible for the telegraphists to *remember* what each sign meant. This was of no consequence at the intermediate stations, where the sign observed was merely to be imitated and recorded by a corresponding written sign; but at the terminal stations some time must have been necessary for looking out in the code the number corresponding with a particular sign, and then referring to the dictionary to ascertain its signification. At the rate of transmission actually attained between distant points, as before stated, this was not found a practical inconvenience; but, for signalling between two points near to each other, it would, doubtless, cause considerable delay, as compared with a more simple system of signal, which can be carried in the memory. The simplicity of the cone system of telegraphing, therefore, makes it better suited for naval and military purposes, when a temporary means of communication is required between posts within a short distance of each other. For longer distances, or a more permanent means of communication, the electric telegraph would now be employed.

The Redl cone system has also been adapted to *two* cones, or other signals, instead of *four*. The 15 symbols made by the 15 permutations and combinations of the four cones are, in this system, represented by *successive* movements of the two cones, one of which is used as the positive (or open cone or dash), and the other as the negative (or shut cone or dot). By this code words cannot be spelt; numerals must be used, to be interpreted by means of a dictionary. It is, however, proposed, in the army signal book, that the dual system, as it is termed, should be used for the electric telegraph, and also for flashing signals by night.

I cannot but regard the dual system as a mistake, and as very far inferior to the Morse telegraph alphabet. In both *successive* signals are necessary to produce a word or a number. With the latter system any two signals—whether cones, flashing lights, flags, or even the arms of a man—can be made available, without the aid of any dictionary, as an expedient to communicate between stations a short distance apart; but, with the dual system, a dictionary is required, and the action of the electric telegraph would, therefore, be rendered very slow; it would, in fact, be brought down to the same level as the imperfect visual telegraphs. The object of using the numerals rather than the letters of the alphabet in telegraphing, is solely to overcome the difficulty of making successive signals rapidly, which shall be distinctly visible at a distance. In all efficient visual telegraphs, therefore, one signal is made, and left visible for some time, until it can be distinctly made out at the distant station, where it is imitated, and so passed on to the next station. Where the signal is brought close to the eye, as in the electric telegraph, the difficulty of observing rapid movements, distinctly, disappears; the necessity of intermediate stations to repeat and pass on the signal is also avoided. The mode of signalling may, therefore, be simplified, the dictionary dispensed with, and the rapidity of communication vastly increased.

About two years ago it suggested itself to my mind that, for a temporary telegraph between two stations not very far from each other, a simple visual telegraph might be constructed, either by two bags, hung vertically above one another, which could be opened and shut at pleasure by cords, pullies, and weights, or by simple balls in the same position, which could be moved up and down in the same manner; one of the bags or balls signifying the dot, and the other the dash, of the Morse alphabet. The wind interfered very much with the action of the bags, but not with the balls. The system worked well for short distances in moderately clear weather; but, beyond a mile, the signals became confused, unless they were worked very slowly; and the strain upon the eyes of the signal man was very great, and there was, in consequence, much liability to error. I am of opinion, however, that the idea is worth remembering, as circumstances may frequently occur where such a mode of signalling would be of much use—for instance, in completing a line of electric telegraph across a river, before an electric cable or air wire could be established; or in communicating between two bodies of troops, divided from each other by any obstacle of moderate extent, such as a marsh, ravine, river, &c. The signals used might be cones, or the bags or balls before described; or banderols raised and lowered; or any such expedient, which could be extemporised with the means at hand, bearing in mind that all semaphore signals should, if possible, be so placed as to have the sky for a background. Connected with the Redl cone system of telegraphs, a small instrument has been prepared for recording the signals, which is very ingenious, and seems well suited for the purpose. I conceive, however, that it will generally be preferable to ascertain at once the meaning of each signal, rather than to trust to the record obtained by means of the instrument, as an additional source of error is introduced, and greater delay and inconvenience will result from a misunderstanding the longer it is left uncorrected.

In the preface to the army signal book to be used with the Redl cones, it is stated that it has been drawn up with the view of facilitating communication between stationary military posts, between military bodies in motion when at a distance from each other, also for supplying a means of communication by signal between Her Majesty's land and sea forces, when engaged in combined operations, and between coast batteries and Her Majesty's ships. It appears to me that the first of these objects—communicating between stationary military posts—will be more properly and advantageously attained by the use of the electric telegraph. In the case of ships at sea communicating with each other, or with troops on shore, we are bound to adopt some sort of visual telegraph, because the necessary conducting wires for electricity cannot be employed; and for communicating between moving bodies of troops on shore it is not often that the electric telegraph can be brought into play, because some time is necessary for connecting the distant points by an insulated wire. Such cases may, however, occur occasionally, even when armies are in motion, as has been well established by the experience of the late campaign in India, when the electric wires were carried along with the army in its advance, and instantaneous communication with the base of operations was continually maintained. Electric telegraph stations were, indeed, in many instances, formed by the officer in charge of the telegraph in the enemy's works the moment they were taken by our troops, and the information telegraphed back to the Commander-in-Chief. In the late Spanish war, in the north of Africa, the electric telegraph was also used to communicate between the advanced posts and the base of operations. These may be exceptional cases; but, in all standing camps, in sieges, for stationary military posts, and extended systems of fortification, such as the improvements in modern firearms are rendering imperatively necessary, the electric telegraph is beyond a doubt the proper mode of uniting under one head the separated elements of the military body; and it would be sad blindness were we not to avail ourselves of the advantages which, in such cases, we gain by the use of electricity rather than any form of visual telegraph. Without considering the very great increase in speed of transmission of messages, which is gained by the use of the electric telegraph, its great advantage is, that at night, or in foggy weather, all visual telegraphs are useless (for I believe that no system of night signals has, as yet, been found practically efficacious), and at the very critical moment of an attack, when the greatest stake may depend upon the rapid and correct transmission of a message from one point to another, the smoke of the guns will inevitably obscure any visual telegraph from the view.

Major Stewart, of the Bengal Engineers, who had the direction of the electric telegraph during the late Indian mutiny, was called upon lately to report upon a system of electric telegraph to connect the various works at Gibraltar. The Commandant at the station advocated semaphores, but Major Stewart gave it as the result of his experience in India that the electric telegraph was immeasurably superior, for the reasons I have before stated—viz., that its working is not interfered with by the smoke of action, or during darkness or misty weather, when the semaphore is useless.

A system of electric telegraph has already been laid down at Malta, where it is in full operation. It is sanctioned for Gibraltar, and will shortly be in operation there; and a line has been constructed between Portsmouth and Gosport, which will be extended to Fort Rowner when it is completed, and eventually, I believe, to all the works in the new line of fortification at that station. Doubtless, the new works to protect our dockyards at Chatham and Plymouth will also be connected by electric telegraph when they are completed, and the disadvantages resulting from the great extent of the works will be, in great measure, nullified by their being all brought within speaking distance of the General Commanding.

That our great fortresses are to be centralized by the aid of the electric telegraph appears, then, a settled point, which is in course of being carried into effect; but the system of telegraph to be used with an army in the field is still, in some degree, unsettled. It is true that in the Crimea the electric telegraph was employed by the British army (which had the honor of being the first to avail itself of this new aid in war). In the Engineer Field Equipment of the Turkish Contingent Force a very complete set of electric telegraph apparatus was sent out, although it was never used, owing to the force not having been actually engaged. Electric telegraph apparatus also formed a portion of the Engineer equipments which were sent to India and China for the late campaigns in those countries; and at *Canton* an electric telegraph was laid down between the landing place and the head quarters of the Army. Moreover, in the scheme which has been drawn up by the Royal Engineer Committee for an Engineer

Field Equipment, an electric telegraph has been included. As it has been before observed, however, many cases will arise where the electric telegraph cannot be employed in active warfare, and when a simple system of visual telegraphs would be very valuable, and the cone telegraph appears the best yet invented for such cases. It seems desirable, therefore, that a proportion of such telegraphs should form an integral part of the telegraph equipment of an army in the field. But although a book has been published by authority describing the manner in which the cone telegraph is to be used, I cannot discover that any arrangements have, as yet, been made for training telegraphists to use it, nor has the service of the army telegraph been placed in the hands of any person, or department, to be responsible for its efficient working whenever an army, or a portion of it, may be called upon to take the field. I am informed, also, that the cone systems of telegraphs, although it was adopted for a time by the Admiralty, and was found to answer well, has been allowed to drop on a change of board; but no fault has been found with the system, as far as I can learn.

On considering the subject, it seems to me best that the telegraph department of our army should be united under one head, and worked by one corps. The electric telegraph has been entrusted to the Corps of Royal Engineers; and, as a scientific corps, they ought, undoubtedly, to be the best able to work it satisfactorily. Having, then, this nucleus, it is reasonable that the whole telegraph department of the army should be entrusted to the same corps, and that our electric telegraphists should be instructed also in the use of the cone telegraph, a suitable light equipment being organized for conveying such telegraphs with the advance of an army. I am inclined to think that to this proposed organization the Quartermaster General's Department might offer an objection, considering the Telegraphic and Intelligence Departments more appropriately to belong to them. There are many instances in which the duties of the Royal Engineer and the Quartermaster General's Departments approach each other closely; but the necessity of having the telegraphic department united under one head must be very evident, and unless a special corps of telegraphists be organized and placed under the Deputy Quartermaster General of the army, I see no better arrangement than to assign the duty entirely to the Royal Engineers, as has been the case with regard to the electric telegraph hitherto.

The propriety of employing Sappers as telegraphists when the electric telegraph has been established at our camps and fortifications is now, however, being mooted. In the correspondence which has taken place relative to the establishment of an electric telegraph between Portsmouth and Gosport, and the adjacent forts, it was suggested by the Defence Committee, that by forming stations in the Brigade Office at Portsmouth, and in the Orderly Room at Gosport, the expense of special telegraphists might be done away with. But in reply it was argued that the clerks in the Brigade Office and the Regimental Orderly Room must undergo a course of training before they are able to use the telegraph, and that the instruments and conductors being liable to get out of order from various causes, it is necessary that some competent persons should always be on the spot to repair them and maintain the communication. That our men are specially trained in these duties, and it seems desirable to give them every available opportunity of carrying out practically what they have learnt, and, by practice, to gain greater readiness and expertness in the telegraphic art, rather than to lose what they have learnt, by disuse. There can be no doubt that clerks in military offices could be trained to these duties, if intelligent men; but the advantage of having a permanent trained staff always available for the electric telegraph service of the army is so great that the small extra expense involved in the working pay of the Sapper telegraphists seems hardly worthy of consideration. At the same time it would be useful to train pensioners, clerks in military offices, librarians, and other non-effective soldiers in garrisons, to this duty, in order that they may be able to take the place of the Engineer soldiers should they be required for active service. Boys are frequently more quick than men in learning the electric telegraph, and are useful auxiliary clerks, although there are few who are sufficiently steady to be entrusted with the entire work of a telegraph office.

As regards the best form of instrument to be used for military purposes some difference of opinion exists. The various forms which have been proposed are as follows:—

1. The single needle instrument, worked by voltaic electricity.
2. The magnetic single needle instrument.
3. The Morse instrument.
4. The letter-shewing instrument of Wheatstone or Henley.

The first mentioned is that which has hitherto been used by the department, and it has great advantages. It is very simple in its construction, and easily repaired; in fact, an instrument quite efficient can be made by any intelligent mechanic. The electricity used, obtained from the voltaic battery, is not of very great intensity; and the perfect insulation of the wires is, therefore, of not such great moment as when the induced current of electricity obtained from magnets is employed. The indications of the needle are so distinct that from 12 to 14 words a minute can be readily sent and received; and as many as 20 words a minute can be read by very expert telegraphists.

The magnetic single needle instrument has the advantage of requiring no voltaic batteries; it is, however, inferior to the first-named in the following respects:—1. The currents of electricity generated by reversing the position of the coils of fine wire on soft iron cores, opposite the poles of the permanent magnet, *must* always be made alternately in opposite directions; it is, therefore, necessary to use the position of the needle when deflected to one side as the zero, and to give the deflections to the other side a longer or shorter duration to signify the dashes and dots, which, when combined, form the letters of the alphabet in the telegraphic code. With the voltaic instrument, the zero of the needle is the central point, the deflection to the left signifying the dot, and the deflection to the right the dash. This is far more distinct, and more quickly read, than the one-sided deflections of the magnetic instrument. 2. The induced magnetic electricity has great intensity, and careful insulation of the conducting wires becomes imperative. This, in military telegraphs, is a condition very likely to be interfered with, and the inconvenience of the voltaic battery appears to be more than counter-balanced by its greater efficiency, under circumstances of defective insulation.

The Morse telegraph is one in which a ribbon of paper unrolled from a drum, at a regular rate, by clock work, is passed under a roller, beneath which is a small spud on one extremity of a lever, the other end of the lever being subject to the attraction of an electro-magnet. The lever is held away from the paper and the electro-magnet by a light spring, but is drawn down to the electro-magnet whenever a current of electricity passes, and the spud at its extremity makes an indentation in the paper longer or shorter, according to the duration of the current. In this way the conventional alphabet of dots and dashes is impressed upon the ribbon of paper, and can be read by the telegraphists. In America very generally, and occasionally in England and other countries, the paper ribbon has been dispensed with, and the communication is read by ear, the lever making a clear rapping sound on an anvil, which conveys to the instructed ear an intelligible language. One great advantage of receiving messages by ear rather than by eye, is that the same person can receive and write the message as he receives it. With the needle telegraph two persons are required, one to read the indications of the needle and dictate the message, and an assistant who writes it; or else the message must be received more slowly, the receiving clerk writing each word after he has received it. On the other hand, however, it must be remembered that great intelligence and talent of a peculiar sort is required both for sending correctly on the Morse instrument, and also for receiving by ear; and that, whether the recording apparatus or the sounder be used, in most cases a relay magnet and a local battery are required to reinforce the electric current, and give it sufficient power to produce a distant sound or to work the recording apparatus. The Morse instrument, therefore, though in many respects superior to the needle instrument, is, nevertheless, more complicated and cumbersome, more expensive, and more difficult of repair, especially when used with the recording apparatus, and it requires more skilful manipulators to work it. For these reasons it does not seem so well adapted for military purposes as the needle instrument.* I should add that the needle telegraph was used for military purposes during the active operations of the late Indian campaign.

The *letter shewing telegraph* has been used for many years on the continent of Europe, and it is a very perfect and beautiful instrument. It has lately been introduced into England, and it has been proposed to be used for military purposes. As constructed by Professor Wheatstone, however, it is exceedingly complicated, and proportionately expensive. A pair of these instruments, supplied for the use of this establishment, cost, I understand, 70 guineas; while a pair of single needle instruments may be purchased for £9 or £10, and can be made in a rough sort of way for as many shillings. Moreover, these letter shewing instruments had an awkward habit of shewing the wrong letter; a T, for instance, when they ought to have shewn Z; and the ingenuity of the Chatham establishment was not equal to the task of curing them of talking nonsense. The instruments have been returned to the maker for re-adjustment, but it is clear that such a mishap would be fatal to the success of the telegraph in a foreign country.* A simpler and less expensive telegraph, of the same description, has lately been patented by Mr. Henley, and it is possible that some such instrument may eventually supersede the old single needle instrument. But the results of experience can be the only true guide in such matters.

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* Special cases may arise in which very long lines of telegraph may be established for military purposes. In such cases the Morse instrument would be most suitable, from the facility with which the electric current may be renewed at intervals, by means of relay magnets and local batteries. The recording apparatus would also be of value in such cases.

Professor Wheatstone's instruments are worked by magnetic electricity. Henley's are of two patterns, the one worked by voltaic electricity, the other by magnetic electricity. Some of all these three patterns of letter shewing telegraphs are now in use in public and commercial offices in London for communicating between distant parts of the city, and they are found very convenient; but, it must be remembered, that the maker is always at hand to remedy any injury or defect.

In the matter of conducting wires, there are differences of opinion and of practice. In the electric telegraph used in the Crimea, an underground wire, No. 16 copper, twice covered with gutta-percha, was employed; it was buried in a trench about 1 foot or 18 inches deep, without any further protection. The wire was frequently cut, or the insulating cover of gutta-percha injured, and the current interrupted from various causes, often by the men digging for roots to use as fire wood, or in the making of roads or drains about the camp. Once the current was totally cut off in the line to Kasatch Bay in a very singular manner; a field mouse chose to establish its nest close to the wire, and, in forming its nest, it bit right through the wire, not only through the gutta-percha but it even severed the copper wire so as completely to cut off the current. In such cases much trouble is necessary to find out the defective place; the wire must be cut in various places, and tested to discover where the fault lies; and if not carefully repaired, these points where the wire has been cut, become in themselves faults in a short time. The gutta-percha covering of the wire used in the Crimea became defective in parts, cracking in numerous places, each of these cracks served as a minute earth connection in wet weather, and there was great difficulty in working the line in consequence. In view of these difficulties, Major Stokes fitted the electric telegraph waggons of the Turkish Contingent Engineers with 10 miles of thin iron wire (No. 16), and a proportion of light porcelain insulators; a few miles of gutta-percha covered copper wire were also carried to be used in places where it would be objectionable to use poles. He trusted to the resources of the country for poles for his air wire. In India, the campaign being carried on in the dry season only, there was but little difficulty in rapidly establishing an air line; No. 8 iron wire was used; and the earth being baked so hard and dry as to be a very perfect insulator, the wire was attached, without insulation, to trees, fences, sticks, and bamboos, or even laid on the ground, and no practical difficulty was experienced in telegraphing through some hundred miles of such a line in the dry weather; during rains, however, it became almost impossible to use it. For the late Spanish campaign, in Morocco, Mr. Henley fitted up a magneto-electric telegraph; and a light insulated copper wire, protected with an outer casing of iron wire, was wound on a large drum placed on a cart. The cable was paid out on the ground as the cart travelled, and an efficient telegraph communication was thus established. I have not been able to obtain the exact details of this arrangement, or of its use, but I believe it arrived in the country only at the close of the war, and was not much used. Such a conductor would be convenient, and, except in a rocky country, would not be liable to injury; but it would be very expensive.*

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* Professor Wheatstone has perfected his letter shewing telegraph since the above was written, and has presented a pair of his improved instruments to the Chatham Establishment in place of those here alluded to. The new instruments are most beautiful pieces of mechanism, and work together perfectly; but in my opinion they are too delicate and complicated for military telegraphs.—H. S.

For the convenience of communication between the range party and the battery in the late Artillery experiments at Bexhill and also at Eastbourne, an electric telegraph was established, and worked by a party of Sappers sent from the Royal Engineer Establishment. The gutta-percha covered wire was found very convenient in these cases. It was attached to hop poles, where there was any traffic, so as to raise it out of harm's way; and where the line crossed waste land or shingle, it was merely laid on the ground. The communication was thus established with great ease, in a very few hours. To have buried an insulated copper wire, or to have supported a bare iron wire on posts, with insulators, would have required considerably more time and labour.

At Malta the whole of the land wires are of copper, coated with gutta-percha, and served with spun yarn; and are laid underground in creosoted timber troughing. This is a secure arrangement for a fortress, if the wires are buried sufficiently deep to be beyond the reach of the enemy's projectiles; but subterranean lines are now being replaced with air wires, by all the telegraph companies who at first used the former. The underground lines were practically found very troublesome and expensive to keep in repair. The system was adopted at Malta on account of the cables across the harbour, which would be liable to injury by lightning, were air wires connected with them without lightning protectors.

At Gibraltar an aerial system of telegraph wires is to be adopted; the rocky nature of the locality almost necessitates this; and, although the wire may be injured occasionally during a siege, the fault is so readily discovered and repaired, that the exposure of the wire ceases to be a disadvantage, as compared with the difficulty of discovering and repairing faults in an underground wire.

For the long spans which are sometimes necessary in carrying air lines over the roofs of houses, or across streams, &c., the Americans use No. 16 iron wire. English iron wire being of inferior quality, we use steel wire for very long spans, or a compound wire of 7 strands of galvanized charcoal iron No. 22, for spans up to 400 yards.

Electric telegraph cables are yet in their infancy, but the boldest and most successful feat in submarine telegraphy yet accomplished was probably the Government cable between Varna and the Crimea, supplied and laid by Messrs.

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* Mr. Siemens has lately submitted to the War Department a specimen of electric telegraph cable, specially designed for military service. The conductor is No. 26 copper, insulated with india-rubber and gutta-percha, and protected and strengthened by two layers of tarred hemp strings, and an outer sheathing of strips of sheet brass overlapping each other spirally, and forming a strong and flexible covering. It weighs 3½ cwt. per mile, and measures ½ inch in diameter. The cost is £38 per mile. It appears to be the most suitable conductor for such purposes that has yet been devised, as it is only flattened by the passage of heavy wheels over it, without sustaining any permanent injury.

Newall and Co. It was only a single copper wire, coated with gutta-percha, and it worked without interruption until the conclusion of the war. The best permanent cable, also, seems to be the Government cable which has just been laid down between Malta and Alexandria, the electrical conduction and insulation of which are far superior to those of any cable hitherto constructed. Many interesting scientific questions are involved in the subject of submarine telegraphy which cannot be entered upon in this paper; but it may be mentioned briefly that cables have been laid across the harbours of Malta and Portsmouth for military telegraphs. They are portions of the same cable having 6 conducting wires, of No. 16 copper, covered with gutta-percha, served with spun yarn and protected with 12 iron wires, No. 1 B. W. guage—the whole weighing 8½ tons per nautical mile. This is a very heavy cable, and is well suited to such positions, where it is liable to be caught by the anchors of vessels; but the most experienced telegraph engineers do not estimate the life of a cable, exposed to the action of waves and tides, as worth more than 10 years' purchase. It is found that the iron coating is rusted and worn through in that time, and the conducting wires become exposed to injury. When an air line is in connection with a cable, a lightning protector is necessary to intercept any powerful charge of atmospheric electricity which may be caught by the air line, and which, passing into the cable, would probably burst through the insulating coating to reach the exterior coating of iron and the sea, and so destroy the insulation. Such conditions exist at the ends of the Portsmouth cable where lightning protectors are accordingly attached. As regards the operation of submerging short heavy telegraph cables, I may mention that the expensive break machinery required for deep sea cables may be dispensed with in such cases. The Portsmouth cable, about ¼ mile long, was coiled 8 fashion, in the square of the Point Barracks at Portsmouth. One end was led out through an embrasure, and being secured on board a steam tug, it was towed slowly across the harbour, the cable paying itself out without any difficulty.

The testing of telegraph cables is a question which is now exciting much interest. In short cables it is practically only needful to test the insulation and the continuity of the conducting wires; but, in long cables, the specific resistance of the conductor to the passage of the current of electricity becomes a most important question. Its importance may be judged from the fact that the conductivity of the ordinary copper of commerce falls as low as 15 sometimes, that of pure copper being 100. Electricians are now endeavouring to fix a standard of resistance with which all conductors may be compared—some prefer mercury, some copper, some other metals, but *pure* copper seems most in favour, as it is the metal which is practically used as the conductor in submarine cables, and the variations in its conductivity at fixed temperatures appear to result entirely from the presence of other metals, or impurities in its substance, which can always be detected and avoided.

A warm controversy is now taking place between the advocates of gutta-percha and of india-rubber as an insulating material. The latter material seems to be generally preferred; but further experience is necessary before a decided opinion can be ventured on the subject. Gutta-percha is, undoubtedly, a very excellent insulator at moderate temperatures, when it is pure; it is, however, frequently adulterated, and is then very worthless. The adulteration of india-rubber is either more difficult, or has not yet been so largely introduced into commerce. At high temperatures, gutta-percha almost loses its insulating properties, and becomes so plastic as to allow wires coated with this material to be forced out of their matrix by moderate pressure. India-rubber is free from these objections, and seems, therefore, the better insulating material for hot climates. A considerable difficulty was at first experienced in applying the india-rubber and in making it adhere to the wire (a separation is objectionable, because moisture intervenes, and the induction is increased), but this difficulty seems now to have been overcome in different ways by Messrs. Siemens and Halske, Messrs. Wells and Hall, and Messrs. Silver and Co. It may be mentioned that ebonite, or hardened india-rubber, manufactured by the last named firm, is one of the best insulating materials known, and is largely employed now in the manufacture of electrical instruments. It is a variety of vulcanised india-rubber and is produced by subjecting sulphurised india-rubber to a high temperature in ovens or high pressure steam boilers for some hours. The sulphur is not eliminated by this process, but appears to enter into more intimate union with the rubber.

As regards conductors for military telegraphs, it may then be stated that they must be suited to varying circumstances of different localities, but that a proportion of insulated wire should always be provided for a military telegraph equipment, and that india-rubber seems to be the best insulating material for hot climates.* If the line be of any considerable length, a thicker conducting wire should be employed than would be necessary for short circuits, when the resistance is small. A proportion of wire, suitable for long spans, should always form part of the electric telegraph equipment of an army in the field; and, in most cases, it will be best to use iron wire for the greater part of the line, supported on poles procured in the country where the army may be operating.

The number of cells of voltaic battery must be proportioned to the length, thickness, and specific resistance of the conducting wire, and also to the dryness or humidity of the climate, as in wet weather, so much of the electricity escapes from the wires, owing to defective insulation, that provision must be made to supply the deficiency thus occasioned. Insulated wires buried in the ground, or submerged in the sea, offer considerably more resistance than air lines, owing to the induced electricity which is generated on the outer surface of the insulating material, and which retards the flow of the current through the wire. The wire becomes, in fact, an elongated Leyden phial, charged with electricity. In telegraphing through considerable lengths of such conductors, a special arrangement of key is now used, by which a positive and a negative current are sent along the wire in very rapid succession; and the signals, which would otherwise be slow and confused, are thus made clear and distinct. The description of battery which appears best suited for military telegraphs is the modification of Daniel's sulphate of copper battery, used at Chatham. The porous cells are dispensed with, and the zinc plates placed above the copper, instead of beside them, as is usual. Its chief advantage is the suppression of the porous cells, which are very liable to fracture, and their pores soon get choked up by the metallic copper which is deposited and by sulphate of zinc. The portability, simplicity, and power of the battery are much increased by this arrangement, and the first cost is reduced; but it is more expensive to keep in action, owing to the more rapid reduction of the copper from its sulphate.

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* The specific inductive capacities of different insulating materials have been ascertained by recent experiments; and india-rubber has been discovered to possess great advantages over gutta-percha, both in the perfection of the insulation it affords, and in the comparatively small amount of inductive charge which is taken up by a long telegraph cable insulated with this material.

In conclusion I must observe that I have felt some difficulty in dealing with so large a subject in the limits of one paper; but I have endeavoured to put briefly before the meeting, the present state, and the apparent requirements of the telegraphic department of our army, with a view to provoke discussion and inquiry on the subject, rather than go into details which belong more appropriately to an instructional lecture.

Since the above paper was written, Captain Bolton, of the 12th Regiment, has proposed to Government a complete system of military telegraphs, embracing a field electric telegraph and system of day and night signals by collapsible cylinders and flashing lights. The chief novelty in his proposal is the employment of the Drummond light for night signals. This light has hitherto been considered too complicated and dangerous for general use; but Captain Bolton appears to have overcome these objections in a great measure. For moveable stations he compresses the oxygen and hydrogen gases into copper cylinders which are carried by the signal-man in a knapsack; the lantern, with its shutter for flashing signals, is carried by the same man, who thus forms an independent station in himself, and can be sent to any point within sight of head-quarters, whence he can communicate as soon as it falls dusk.

In Captain Bolton's system of electric telegraph, the American system of receiving by *sound* has been adopted. This instrument is made to fit on the shoulder, close to the ear, and the slight "clicking" sound of the armature of an electro-magnet is made more audible by the addition of a sounding board. The conducting wires are formed into a small cable or cord; two thin copper wires, insulated with india-rubber, and a return wire of iron uninsulated, being bound up together, sewed with tape, and encased in mohair, so as to present the appearance of ordinary window blind cord. The practical success of this system of electric telegraph has not yet been tested; but the signal-lamp with the Drummond light has been successfully used in flashing signals between Sheerness, Bluebell Hill, and Chatham, and other points in the vicinity.

In a letter received lately from Lieut. Colomb, R.N., it is stated, as the result of some years' experience, that no system of signalling with lights, cones, &c., which depends upon spelling words, can be relied upon, if a communication is to be sent to several stations at the same time. It is necessary in such cases that each signal should be repeated several times until it is made out and acknowledged by all the stations; and for this purpose he has found it advisable to have an arrangement like a barrel organ, which can be *set* to a particular signal, and by merely turning a handle the signal is repeated as often as may be necessary. For naval signals this system is more particularly necessary, owing to the motion of the ships, and the occasional obscuring of the signals by the rigging or passing vessels. It is evident that in such cases *numbers* and a code of signals must be used instead of the method of spelling words.

As regards the cone telegraphs, some difficulty has been experienced in constructing collapsible cones which will open and shut perfectly in all weathers, and which are not liable to get out of order, and the system has not yet been perfected.

I have learnt through Mr. W. Siemens, that in the Prussian and Austrian services a Field Electric Telegraph has been organised. The conducting wire is of copper, and it is supported on small insulators attached to the tops of light poles like lances shod with iron, and which are carried by soldiers, and stuck into the ground at about 50 yards apart along the line of the required telegraph. The insulators are of Messrs. Siemens and Halske's patent form, in which the porcelain is protected by an iron cap. Magnetic letter-shewing instruments of Messrs. Siemens and Halske's pattern are generally used.

H. SCHAW.

PAPER VI.

ON IRON-PLATED SCARPS.

BY LIEUTENANT MILLAR, R.E.

In all systems of fortification it is an acknowledged principle to present to an enemy *successive* obstacles of such a nature that he is forced to destroy one before commencing the operations for destroying another. This principle shews the weakness of detached walls placed in the ditch, unless perfectly covered from distant fire, for the enemy can destroy them while counter-battering the faces opposed to him, as shewn by the experiments at Woolwich in 1824. Even well covered, solid, or counter-arched scarps, can add but little additional security to a work provided with a good counterscarp, now that shot of above a hundred pounds weight are likely to be components of a siege train; because the time occupied in forming a gallery of descent to the base of the counterscarp can also be used in breaching the scarp, and consequently these obstacles cease to be successive. The natural result of these considerations seems to be that we must either replace the scarp, as Captain Tyler, R.E. has recently proposed, by a second glacis and counterscarp, or else find means to render the scarp less destructible.

The following is an attempt to describe a scarp which cannot be breached by distant fire, nor yet by batteries on the crest of the glacis or in the covered way. The only methods by which this obstacle can be overcome are escalade and mining, neither of which can be considered practicable, even after the counterscarp has been blown in, as long as the fire of the flanking caponier or casemate remains unsubdued. This latter, being the hinge or cardinal point upon which everything turns, will of course be rendered secure to the last moment by a liberal use of iron or other suitable materials in its construction. It has been found by recent experiments that wrought iron plates of about four inches thickness will resist shot if they strike at angles of 40° and under. If we then describe the curve of the face of the wall, in profile, so that the tangent at any point may make an angle of 40° with the line joining that point with the top of the counterscarp (as C A in the profile), we may hope by plating the surface with iron to obtain security against any fire which may be brought to bear upon it, since no shot will penetrate it. The revetment, in the accompanying drawing consists of a framework of curved iron ribs placed upright at horizontal intervals of four feet with another line of framework in rear, the outside and inside frames being tied together by wrought iron tie-rods, and braced by horizontal bars. The side of the framework next the ditch is proposed to be covered with four inch plates, and that next the parapet with half-inch plates. A row of wooden piles, 18 feet long and 1 foot square in section, placed at intervals of 2 feet from centre to centre, and driven 10 feet below the bottom of the ditch, would serve to give additional stability during the consolidation of the earth of the rampart, and also to connect the wall with its foundations. The space inside the iron casings should be filled with good solid concrete, composed of clean shingle laid in layers 6 inches thick, and the interstices filled up with a thin mortar or grout made of sand and cement in equal proportions. The following is a practical method of describing the curve of the scarp.

Let A B be drawn at an angle of 40° with A C up to the level of the required height of scarp. About the triangle A B C describe a circle, cutting A D (which is perpendicular to A B) in D. With D as centre and D A as radius, describe the arc A E which will be the curve required. The angle C E D, which the shot makes with the perpendicular to the curve, will then be greater than C A D, the angle at the bottom, by the small angle E C F, and diminishes gradually down to 50° (90°—40°) at the bottom. Above the wall the rampart slopes at an angle of 45°, and is faced with brick on edge laid in cement to a height of ten feet, as in one of the new forts near Gosport. The broad berm which is occasioned by this form of revetment, may be occupied by a "chemin des rondes" or two stout hedges, the space between which may, perhaps, be flanked by a haxo-casemate. The exact curve to which the escarp should be moulded, in order that its tangent at any point may make a constant angle with the course of a shot from the crest of the counterscarp may be found thus:—Let E be any point in the curve. Let the angle D C E be θ, C D $= d$ and C E $= r$ (the radius vector). Let C A B, the constant angle which the tangent makes with the line of fire, be equal to α.

$$\text{Then } r\frac{dr}{d\theta} = -\tan\alpha$$

$$\frac{d\theta}{dr} = -\frac{1}{r}\tan\alpha$$

$$\theta = c - \tan\alpha . \log r$$

$$\text{But when } \theta = 0,\ r = d$$

$$\text{hence, } 0 = c - \tan\alpha . \log d$$

$$c = \tan\alpha . \log d$$

$$\text{or} \begin{cases} \theta = \tan\alpha . \log\dfrac{d}{r} \\ r = d\,\epsilon - \theta\cot\alpha \end{cases}$$

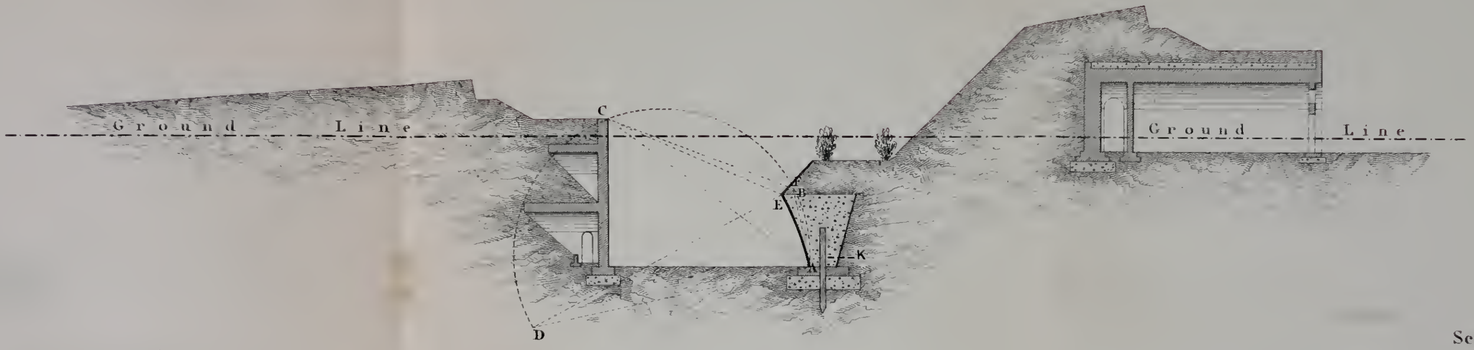
Either of these last may be taken as the polar equation of the curve. In the example in the drawing,

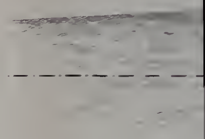
$$d = 50$$

$$\tan\alpha = \tan 40° = \cdot 8391$$

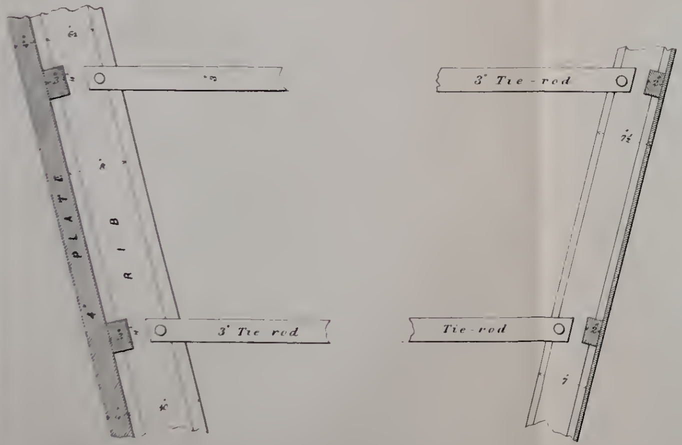
SECTION OF PROPOSED ESCARP.

Scale $\frac{1}{360}$



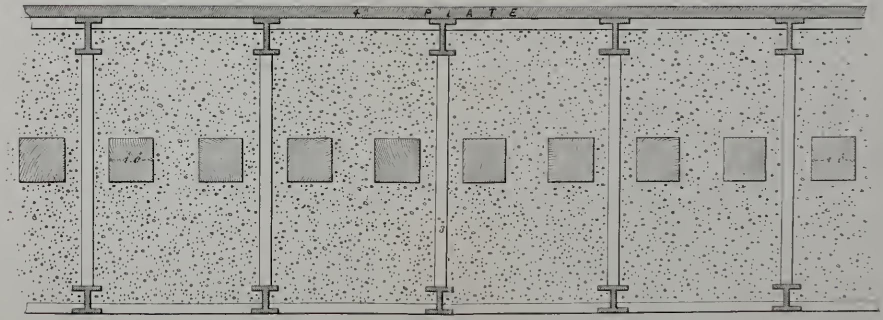


Scale, 30 Feet to 1 Inch.



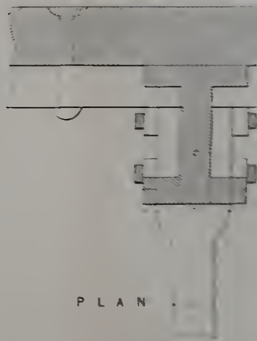
VERTICAL SECTION.

Scale $\frac{1}{20}$



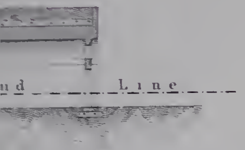
HORIZONTAL SECTION AT K.

Scale $\frac{1}{40}$



PLAN .

DRAWINGS OF

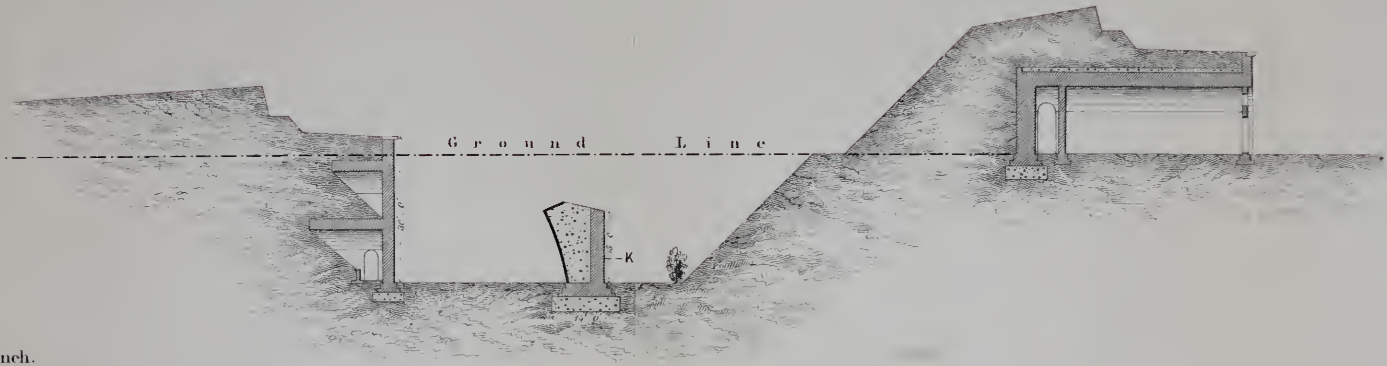


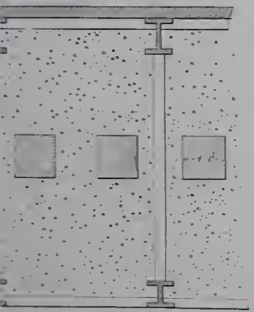
Scale, 30 Feet to 1 Inch.

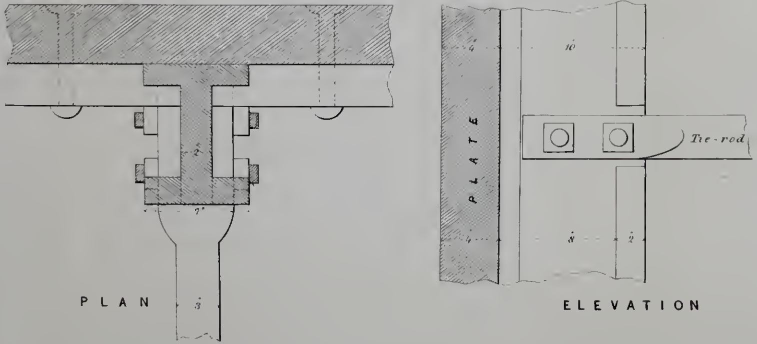
PROPOSED DETACHED WALL.

PROFILE.

Scale $\frac{1}{360}$

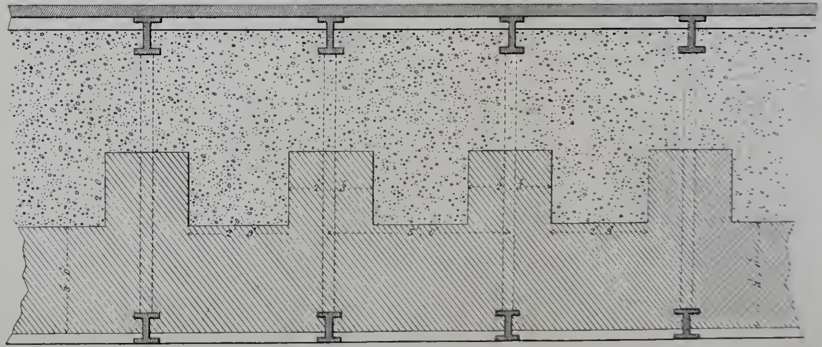






DRAWINGS OF VERTICAL RIB & TIE-ROD.

Scale $\frac{1}{10}$



HORIZONTAL SECTION AT K.

Scale $\frac{1}{48}$

Hence,

$$\log_{\epsilon} \frac{50}{r} = \theta \times \cdot 8391$$

where θ is expressed in circular measure. Reducing θ to degrees, and the Napierian to common logarithms, we obtain

$$\log_{10} \frac{50}{r} = \cdot 009034 \times \theta^{\circ}$$

from which, with the assistance of a table of logarithms, the curve can be easily traced. It is a logarithmic spiral, making an infinite number of revolutions about C, and always approaching that point without ever reaching it. The height of the escarp may of course be increased, but as the scaling ladders would have to be brought down the gallery of descent and put together under fire in the ditch, 15 feet will probably be a sufficient height of scarp for all practical purposes. Pending the conclusion of experiments on iron plates, the dimensions given in this paper must be taken as only approximate, and the expense of the profile proposed in the drawing is perhaps too great for lines of long extent or inferior importance; but it may be suggested that the principle developed above is applicable to the ditches of keeps and retrenchments, or to the more exposed salient points of extensive works.

J. A. MILLAR, Lieut., Royal Engineers.
July, 1861.

PAPER VII.

NOTES ON THE CAMP OF CHÂLONS-SUR-MARNE.

BY CAPTAIN MARTINDALE, R.E.

September, 1861.

In the spring of the year 1857, the Emperor of the French decided upon the formation, in the following autumn, of a camp at Châlons-sur-Marne for about 30,000 men.

Establishment of Camp.—The camp was accordingly established towards the end of August, and was occupied till early in October, 1857, by the Imperial Guard. The force assembled consisted of two divisions of Infantry, a division of Cavalry, with Artillery, Engineers, and the Administrative Services. It amounted to about 6,000 horses and 22,000 men, under the command of the Emperor in person.

Present occupation.—Since 1857, the encampment has been annual, the troops occupying the same ground. The main body are present from about the 1st June to the 1st October. A certain number remain in charge during the whole year.

Situation and character of Land.—The ground selected for the camp lies between the Vesle and Suippes rivers. Its eastern boundary is the high road from Nevers to Sedan. The formation is chalk, covered with a very thin layer of soil. Scattered over the ground are numerous copses of the "pin sylvestre." the fallen leaves from which tend to improve the soil, while the woods themselves are of use in the "manœuvres" which constantly take place.

Branch Railway.—The right of the encampment rests upon Mourmelon-le-Petit, which is connected with Châlons on the line of railway from Paris to Strasbourg by a branch line, 27 kilomètres (about 16¾ miles) long.

The whole of the land was taken in 1857, including an extension of the northern boundary, through which runs the River Suippes. This was required for additional manœuvring or bivouacking ground. The area is 9,200 hectares, or 22,734 acres.

Cost of Land.—The entire cost, capital, interest, and expenses included, will amount to 5,500,000 francs, or about £220,000, between £9 and £10 per acre;* but the whole sum will not be paid till 1865.

Compulsory taking of Land.—A small part of the land was obtained amicably on reasonable terms. The price asked for the remainder by the very numerous small owners was such as to render it necessary to take it compulsorily, under the "Loi sur l'Expropriation pour cause d'utilité publique, 3 Mai, 1841."

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* £9·677 per acre.

Improvement of Land by Farms and Gardens.—The ground is naturally very poor *(pouilleuse)*, but considerable efforts are being made to improve it. There are eight farms of from 500 to 750 acres each, commenced and maintained by the Emperor himself. Along the entire length of the encampment, there are also, first, a space varying from 25 to 60 mètres (82 to 197 feet) wide laid down in grass,† and then vegetable gardens, about 50 mètres (164 feet) wide. These extend from the officers' quarters to the rear. The grass is a relief from the glare of the white roads, and the produce of the gardens forms a valuable addition to the men's mess.

The grass and gardens were first laid out by the Engineers. Under their general direction they are maintained entirely by the troops. The cost to Government does not exceed £50 a-year. Arrangements have been made to enable the troops to receive the benefit of them as soon as they are encamped yearly. To effect this, hot-beds are carefully attended to by the Engineers during the winter. At the beginning of April a detachment of 1 sergeant and 15 men from each regiment to be encamped arrives in advance. These detachments are employed by the Engineers in planting out the vegetables and attending to the gardens for their several regiments.

Scattered throughout the camp, amid the tents, are small flower gardens maintained by the men, and ornamented with models and statuettes cut in chalk, their handi-work.

Lodgment of Troops.—During the first encampment, in 1857, the troops were in tents of two kinds, with wooden huts for the officers' mess, the canteens, kitchens, officers' stables, and latrines. There are now brick huts built or building for a division of Infantry, with partial accommodation for the Staff, Engineers, Hospital, and Administrative Services. The remainder of the troops are lodged as at first; nor is it intended to alter this, further than by replacing the wooden buildings, as they require renewal, by brick buildings.

The present encampment stretches in a curved line along the banks of the little rivulet De Cheneu, from the railway station of Mourmelon-le-Petit to more than a mile beyond Mourmelon-le-Grand. It occupies the south-western corner of the Government ground. On the extreme right, in tents, is the 1st Brigade of the 1st Division of Infantry; next are four regiments of Lancers, and a small detachment of Chasseurs à Cheval. In front of the Lancers, between them and the wood, are four regiments of Cuirassiers. These only arrived about the middle of August. To the left of the Cavalry, separated by an interval, is the temporary Hospital for 400 patients, occupying the brick huts originally built for a battalion of Chasseurs à Pied. Separated from the Hospital by the road leading to the Quartier Impérial, is the 2nd Division of Infantry. Of this the 10th Battalion of Chasseurs à Pied, and the 82nd and 83rd Regiments forming the 1st Brigade, and the 89th Regiment of the 2nd Brigade, are in brick huts. The remaining regiment, the 98th, is in tents, separated from the 89th by the huts in course of construction. On the left, is the 3rd Division of Infantry, under tents.*

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† The grass stretches from three or four feet in front of the officers' quarters to the street in rear of the stables, thence the gardens.

Between the Cavalry and the temporary Hospital, but somewhat in rear, are the Engineer offices and workshops, quarters for the Commanding Engineer and Executive Officer, and for a company of Sappers, with a mess-house. These are in brick. The remaining two companies of Sappers and a mounted detachment are in tents.

In rear of the right of the Cavalry and of the 2nd Division of Infantry, are two "Ambulances," or brick hospitals, for 100 patients each. A third is in rear of the centre of the 3rd Division.

Near the second ambulance are the general prison and a Protestant church in course of construction.

About 750 yards in front of the line on rising ground commanding the camp, are the Quartier Impérial, and the quarters and offices of the Marshal and Etat Major-Général.

Returning to the extreme right, in a second line separated from the first by the De Chenu rivulet, is a demi-brigade of the 1st Division of Infantry, under tents. On their left are the horses, waggons, and men of the "Train des Equipages." In front of these a brick hospital is in course of construction for 100 patients. To the left are the quarters, offices, workshops, and stores of the "Services Administratifs." Then comes the remaining demi-brigade of the 1st Division.

Twelve batteries† of Artillery complete the second line; their left is in rear of the Engineers' camp, and rests upon Mourmelon-le-Petit. They are all under tents.

Some distance in rear of the Artillery are their "arsenal" or shops and stores for repairs, a small canteen, and stable, "salle d'artifice," store for wood and iron, and the powder magazine for the entire camp.

Between the first and second lines are the quarters of the general officers commanding the Artillery, Cavalry, and 1st Division of Infantry.

Summary of present Encampment.—There are, therefore, 9 regiments of Infantry, 8 regiments of Cavalry, 12 batteries of Artillery, 2 companies of Engineers, 2 battalions of Chasseurs à Pied, and the major part of the "Train des Equipages," and "Services Administratifs," encamped in tents. There are 1 battalion of Chasseurs à Pied, 3 regiments of the Line, 1 company of Engineers, 1 company Train des Equipages, in huts, with workshops, hospitals, stores, and quarters and offices for the General Staff.

Strength, 32,000 men.—The total force present was estimated at about 32,000 men, including the Cuirassiers.

Two descriptions of Brick Huts.—The hut encampment is composed of two descriptions of brick huts; the one built in what is termed "briques cuites," the other in "briques crues."

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* Of this division, the 103rd Regiment, the new regiment of Savoy and Nice, occupies the extreme left, in a secluded and pretty encampment, amidst woods, small gardens, shrubs, and flowers, models and statuettes in chalk, unusually well executed by the soldiers themselves.

† An additional battery was expected, but had not arrived when I left the camp.

The former are kiln-burnt bricks from the neighbourhood of the hills about Rheims. They average 0·22 × 0·11 × 0·05 mètres (8·6 × 4·3 × 1·97 inches) each; and are worth from 46 to 50 francs (36s. to 40s.) per 1,000, delivered in camp.

The latter are made of the soil on which the camp stands, moulded and dried in the sun; the length of exposure depending upon the weather. Their size is 0·32 × 0·16 × 0·088 to 0·10 mètres (12·2 × 6·3 × 3·1 to 3·9 inches); and their cost per 1,000 about 10 francs, or 8s.

Description of Brick Huts.—All the huts first constructed were in "briques cuites," in timber framing—what in English is termed "brick nogged." The thickness of the walls is under 4½ inches, the window and door sills, jambs and lintels, of wood.

Complaints were made of these huts as hot in summer, and damp and cold in winter.

The "brique crue" construction was therefore substituted. The foundations are of rubble stone in mortar carried to a height of about 3 feet above the ground. The walls are of "brique crue" 0·50 mètres (rather more than 18 inches) thick. The bricks are built in with slime made of the soil on the spot. The walls are cemented outside with good "cement de Vassy," and plastered within. The jambs and arches of the windows are in "briques cuites," the window sills and door steps of hard stone, the door jambs of stone and brick, or all stone.

Both descriptions of huts have (with a few exceptions of brick-paved floors) boarded floors, and roofs slated on boards. Nearly the whole are furnished with rain water pipes and gutters.

Huts in "briques crues" preferred. Cost.—The "briques crues" huts are found much the more comfortable of the two. They are somewhat more expensive; for the cost of a soldier's hut to accommodate 50 men and 6 sous officiers, in "briques cuites" is only 6,700 francs, or £268, and in "briques crues," 7,200 francs, or £288.*

Gradual construction by military as well as civil labour.—The construction of the huts has been gradually and inexpensively carried on from year to year, and is still in progress. The whole of the carpentry and joinery has been executed by the Sappers and other military workmen. For building and slating civilians are employed, as more economical, notwithstanding the higher wages paid to them.

Design of Hut Barracks.—The huts first built were designed for regiments of two battalions of 800 soldiers each. There were therefore 16 soldiers' huts in two rows for each battalion, each hut capable of accommodating 6 sous officiers and 50 men.

Occupation of Huts.—This arrangement does not agree with the organization of the regiments in camp. The occupation as a temporary hospital of the huts built for a battalion of Chasseurs à Pied also disturbs it. Thus there are a battalion of Chasseurs à Pied and three regiments of the Line, of three battalions each, in the huts designed for three regiments of two battalions of 800 soldiers each. The original arrangement is, however, still carried out in the huts in course of construction.

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* General plans of the camp and detail plans of some of the principal buildings accompany these notes.

Huts required for a Division of Infantry.—Under it the following are the huts provided for a division of infantry, consisting of 1 battalion of Chasseurs à Pied and 4 regiments of Infantry :—

144 Soldiers' Huts.
38 Huts, Petit Etat-Major, kitchen, canteens, workshops, stores, band-room, guard, and lock-up, and cantinières' and washerwomen's rooms.
18 Huts, officers' quarters.
5 Huts, superior officers' quarters.
5 Mess huts.
2 Huts, Generals of Brigade.
1 Hut, Chef d'Etat-Major.
1 Hut, General of Division.
2 Ablution sheds.
8 Stables.
5 Officers' latrines.
9 Soldiers' latrines.

Strength of Division, 8,940 men.—The strength of the Division, including staff, may be put at 8,940 men.

Cost.—The cost of hutting a division does not, it is stated, amount to 200,000 francs or £80,000. The expense per man at this rate would be nearly £9 (8·948) for barrack accommodation only. Monsieur le Commandant Weynand, Chef du Génie, under whose able direction the entire camp has been constructed, places it at £8 per man.

Huts built and building.—Of the existing huts, those for two regiments are in "briques cuites," and for one regiment in "briques crues." The huts in course of construction for the fourth regiment are also in "briques crues."

Non-commissioned Officers' and Soldiers' Huts.—The soldiers' huts are about 99 by 20 feet, internal dimensions. Of this 87 by 20 feet forms the soldiers' room, and 11·6 by 20 feet that for the sous officiers', separated from that for the soldiers by a partition about 6 inches thick.

These dimensions give 34·8 super. feet for each soldier, allowing 50 men to the room, and 38·6 for each sous officier, allowing 6 to the room.

The buildings are ceiled to the collar. Taking 9 feet as an average height, we have 313·2 cubic feet per soldier, and 345 per sous officier. In practice, however, in the camp the smaller room is generally occupied by one sous officier; at most by two.*

Kitchens.—The arrangements for cooking are as simple as possible. The apparatus consists of a "marmite" (boiler) on a fourneau" (camp grate). Each

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* The men have separate wooden bedsteads and wooden shelves. The room is heated in winter by a stove, the pipe of which is led into the flue of the fire-place of the sous officiers' room, which is also heated by a stove placed in the fire-place in winter. The floors are raised about 14 inches above the ground.

"marmite" holds 50 litres (about 11 gallons). The "fourneau" is a moveable iron stove on three iron legs. The cost of the whole is as follows:—

	francs.
Fourneau	28·34
Marmite	16·00
Cover of ditto	3·00
	47·34 or 38s. nearly

The allowance of wood or coal is—

	Wood.	Coal.	
For cooking food by fire, per day		30·865	lbs. avoirdupois nearly.
For preparing coffee, ditto, ditto	8·8 or	6 6	lbs. ditto.

The whole cooking is by boiling. The men have coffee the first thing in the morning, and soup at 9½ A.M. and 5 P.M.[*]

No Ash-pits.—There are no ash-pits as in England. The refuse of the kitchen is collected by the men, deposited in a place pointed out by the Engineers, and sold by the men "pour la soupe," in other words to improve the ration. In England contractors are usually paid to remove it.

Canteens.—The kitchens are in the same building with the canteen, one on either side of it. There are two canteens to each battalion. Each canteen has 3 rooms and a cellar. One is a tap-room, the other two are for the cantinière, the wife of a soldier. The sous-officiers mess in the tap-room; the cantinière cooks for them.

Accommodation for Women and Children.—The accommodation for women and children appears limited to 2 cantinières and 2 rooms for washerwomen, per battalion.

Officers' Mess.—The officers' mess is so constructed as to permit of the three grades, field-officers, captains, and subalterns messing separately. In camp all mess together.

Stables.—The stables are double, divided by a partition up the centre. The horses stand head to head. The stalls are not paved. Bails separate the horses, to which are commonly attached small straw mats. The mangers and racks are of wood; the walls brick nogged; the roofs tiled.

Latrines.—The men's latrines have no seats. Holes cut through the floor communicate with barrels placed underneath, which are removed daily by a contractor, who receives one sous per man per month for their removal and the supply of barrels. All the latrines that I saw were very dirty.

No Urinals.—There are no urinals.

No Drainage nor Sewerage.—There is no underground drainage nor sewerage.

"Phare."—In front of the centre of the division is a lofty framework of wood called a "phare." On the platform at its summit are placed 12 lanterns, lighted at night. There are no other external lights, with the exception of lanterns at the latrines.

No Gas Works.—There are no gas works.

The Quartier Impérial and quarters of the Etat-Major-Général are well lighted by oil lamps, when the Emperor is in the camp.

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[*] The men had about 1 litre = 1·76 pint of soup each time.

System of "Corvée."—No expense has been incurred for the formation of ground and parades. Under the French system of "corvée," the troops are bound to give 4 hours' labour per day* to the State without payment. The men are furnished by the different regiments on the requisition of the Commanding Engineer. By this means roads are formed, ground levelled, and ditches cut at little or no expense. I understood, when I was in the camp, that 900 or 1,000 men were thus employed daily. They work by task very handily, and as far as I saw very cheerfully.

Water supply.—Water is supplied by means of wells and pumps, two to each battalion. They vary from 7 to 10 mètres (23 to 33 feet) in depth. At the Quartier Impérial the wells are 30 mètres deep (98 feet). In 1858 and 1859 there was a scarcity of water; the supply is now said to be ample.

Ablution Sheds.—The ablution sheds (*lavoirs*) are two square open sheds erected over wells, one for each brigade.

Camp not a permanent Barrack.—Everywhere the object has been kept in view of making a marked distinction between a camp and a permanent barrack. It is on this ground, Monsieur Weynand informed me, that the huts are not made two stories high.

Temporary Hospital for 400 Patients.—The huts built for the battalion of Chasseurs à Pied are said to answer excellently for the purpose to which they are applied, viz., a temporary hospital.

There are 16 soldiers' huts, each appropriated for 25 men in the large room, and 2 to 4 men in the small room. When officers are admitted the number in each room is less.†

This appropriation gives nearly 70 feet super. per man, and 627 feet cube in the large room, and from 115 to 57 feet super. and 1035 to 517 feet cube in the small room.

The wards were very sweet and clean.

At each end a wooden porch has been built for a latrine, in such a way as to leave an intervening passage. The arrangements are indifferent.

The only complaint made in reference to the accommodation was, that the distance between the huts rendered the service somewhat difficult.

The six huts built for the Petit Etat-Major, kitchens, &c., are occupied (commencing from the left), the first as a kitchen, the second by the "Aumôniers," the third as a chapel, the fourth as the mess-room of the "Infirmiers," the fifth for baths, and the sixth as the "Pharmacie." The officers' quarters in rear are occupied by the "Officiers d'Administration," and the "Officiers de Santé," including the principal medical officer.

The stable has been converted into a dead-house; and a small stable for two horses has been built for the principal medical officer. The latrines were cleaner than usual, but of the same construction.

Ambulance.—To the right of the hospital‡ are tents for cases of itch, or offensive cases; for the "infirmiers" (permanent sick orderlies); for the corporal in charge, and for the hospital guard.

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* This was also stated to me as six hours. Artisans are exempted.

† Officers are admitted at their own request.

‡ While inspecting the temporary hospital, my attention was drawn to the "voitures d'ambulance" and the "caissons de pansement." Of these latter there are two for each division. Each holds twenty-one boxes. Each two boxes contain everything necessary for dressing wounds, arranged in drawers and on little shelves. Each caisson contains 2,000 "pansements." The particulars relating to this service are to be found in an official pamphlet, entitled "Service des Ambulances, Caisson Unique; adopté par décision Ministérielle du 20 Août, 1854.

Besides the temporary hospital, there are the three ambulances.

Each ambulance is built of brick round a rectangle. Three sides are formed by three wards, designed for 40 patients each. These are partly occupied by stores, and the principal medical officer placed the accommodation at 100 men in each ambulance.

Bath rooms and latrines are attached to each ward. On the fourth side is a building containing the kitchens and stores.

Infirmary Tents.—In addition to the hospitals, there are infirmary tents. Each regiment in camp has a large tent of special construction, used as an infirmary. To this men are sent whom the regimental surgeons do not consider sufficiently ill to be sent to the ambulances. In the infirmary the men are attended by the regimental surgeons. Attached to the infirmary there are, an elliptical tent used for a "salle de visite," pharmacy, and quarters for the corporal in charge, tents for the "infirmiers" and for the hospital guard.

Hospital for 100 Patients in course of construction.—There is also in course of construction in front of the "Train des Equipages," a hospital for 100 patients. It is a two-storied building, with four brick huts attached, containing kitchens, offices, and quarters.

The proportion of sick was stated to be very small.

Voitures d'Ambulance.—Voitures d'ambulance convey the sick daily from the infirmary tents to the ambulances.

Venereal cases are sent to Châlons, Nancy, or Metz, every Tuesday and Saturday.

General Prison.—The general prison, near the second ambulance, is a brick building. It contains two rooms, one on each side of a passage. Two guard beds nearly fill each room, which is intended to contain about 40 persons. Out of each room is a small closet, used as a latrine. At the end of the passage is a dark cell. The windows of the prison are guarded by iron screens.

Near the prison are two brick huts, for warders, and tents for the guard.

Men are confined in the general prison for sentences not exceeding 30 days.

Protestant Church.—In front of the prison a Protestant church is in course of construction. The interior dimensions are about 75 feet long by 33 feet wide. The walls are brick-nogged. The principals are tied together with iron rods.*

Quartier Impérial.—The Quartier Impérial contains accommodation for the Emperor, Empress, and Prince Imperial, their suite and attendants; detached huts, for guests; the necessary kitchens, stables, and out-offices, and barracks and stables for a portion of the "Cent-Gardes." The expense, amounting to 150,000 francs (£6,000), was defrayed from the Civil List.

Marshal and Etat-Major-Général.—Separated by the road from the Quartier Impérial are the quarters and offices of the Marshal commanding the camp, and of the Etat-Major-Général.

Field Altar.—In advance of the Marshal's quarters is a field altar, where Mass is said on Sundays and other special occasions.

Engineer Establishment and Quarters.—The Engineer establishment is built of brick, round a rectangle about 450 feet by 360 feet (by scale). It contains carpenters', joiners', tin-smiths', and smiths' shops; quarters for the Commanding Engineer and Executive officer, and five or six Gardes du Génie; a stable, and store-rooms. In the latter were the usual stores required for engineer purposes in a camp, including barrack-stores; and three fire-engines.

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* There are five windows on each side. The entrance is at the west end, with a window on either side.

In the yard was a depôt of wood, for the construction and repair of buildings, waggons, &c., and a wooden carpenters' shed in the centre.*

Construction and Maintenance of Camp.—Everything connected with the construction and maintenance of the camp is under the control of, and conducted by, the Commanding Engineer, with military assistance only, so far as I could ascertain. Where civil labour is employed, as in building the huts, it is by contract.

Library.—In rear of the 2nd Division is a library, built in brick (*crue*). The books are gifts from the Emperor and the Minister for War.

Theatre.—In Mourmelon-le-Grand is a theatre, which is maintained at the cost of the Emperor, and to which officers and men have free admission, according to roster.

"Services Administratifs."—The buildings for the "Services Administratifs" are divided as follows, viz. : for—

L'Hôpitaux.
L'Intendance.
La Manutention.
L'Habillement et Campement.
Le Fourrage.

"L'Intendance."—Those for the "Intendance" consist of quarters and offices for the "Sous-intendant" and "Adjutant," with a two-stalled stable." They lie to the right of the "Manutention."

The quarters and offices of the Intendant are with the Etat-Major-Général.

"La Manutention."—The "Manutention" has stores for wine; brandy; coffee, green and roasted †; sugar; flour, and bread. The stores are weather-boarded buildings, covered with zinc. Their construction is as rough and inexpensive as possible.

The ovens form the front of the bread-store, and are 12 in number. They have brick bottoms, iron sides, tops, and smoke-flues. The iron-work is sent to the camp, packed in boxes.

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* The Engineer Quarters for one company are on the left of the workshops. They consist of four huts for the men and sous officiers, one canteen and kitchen, one troop stable, one officers' hut, and one latrine. The Mess Establishment for the Engineers is also here.

† The coffee is roasted in a small shed adjoining the store, in iron cylinders (called *brouilloirs*), turned by hand over a small moveable grate heated by wood. Each "brouilloir" contains five or six kilos. (12 lbs. avoirdupois), and is filled and emptied ten times a day of ten hours' work. The coffee, when roasted, is placed in a tray to cool, and then packed in cases, and placed in the same store. The gross and nett weights are marked on each case. There are about twenty men employed on this duty, and eleven brouilloirs.

The earth is sustained in front and round the ovens by brickwork. The front and sides of the hut over this are glazed. The roof is tiled. The bread is made in the same room it is baked in.*

It requires 14 men, viz.—1 sergeant in charge, 2 corporals, and 11 privates, to erect an oven in 12 hours.

Perpendicular to the line of ovens, and on their left, are workshops of wood, covered with zinc. Opposite to these are offices, and a magazine for flour.

"Habillement et Campement."—The branch "d'Habillement et Campement," is in rear of the "Manutention," separated from it by a wide road. Along this road, starting from the "Manutention," is a light tramway, which runs along the entire length of the camp. Upon this are conveyed, by horse traction, all articles issued to the troops. The tramway does not join the neighbouring line of railway. Two excellent brick and stone storehouses†, two stories high, a good shed for a workshop, convenient quarters and offices in brick, and some large rough wooden store-sheds in one group, and some wooden huts for tinsmiths' and smiths' shops, kitchens, and mess-room in another group, are the buildings at present provided for the department "d'Habillement et Campement."

Wood Yard.—To its left is a wood-yard, occupied by a contractor.

Forage Stores.—In its rear is the department "des Fourrages." This has an excellent store, with brick ends and open front; also, a wooden storehouse. The surplus forage is under tents, or stacked.

Water, in case of fire.—Here, in addition to the usual wells, casks have been sunk in the ground, to facilitate the supply of water in case of fire.

"Train des Equipages."—To the right of the huts of the department "d'Habillement et Campement," are barracks and stables, in brick, for one company of the "Train des Equipages."

Artillery Workshops and Stores.—On the extreme right of the Artillery, considerably to the rear, is the "Arsenal," or workshops; a building in brick *(crue)* with stone quoins and dressings, finished with unusual care. It contains, in two stories, quarters for two "Gardes d'Artillerie," and an office; and, in one story, smiths' and carpenters' shops,‡ a store-room,§ and a room for the examination of guns. Its length is about 100 feet, its breadth about 22 feet. In its rear is a small wooden stable, and in its front a canteen, with a couple of tents, one for the workmen and one for the cantinière.

"Salle d'Artifice" and Store.—Between these and the powder magazine are a small "salle d'artifice," a brick-nogged building, with tiled roof; and a store-hut, of wood, for iron and wood for repairs.

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* Each oven will contain 84 loaves of two rations each (about 3·3 lbs. avoirdupois), and will make from 1,260 to 1,344 loaves per day of 24 hours.

The present establishment could, therefore, turn out rations for about 32,000 men daily.

The gang for each oven consists of one corporal and four men, with one serjeant for each six ovens. There are gangs for day and night work; but once a week, in order to change the hours, the gangs work for 24 hours together.

† The cost of the two store-houses was £4,680. An equal amount of store accommodation was to be erected, which would provide for 40,000 men in all.

‡ With a field lathe.

§ Containing shovels, pickaxes, &c.

Powder Magazine for Camp.—The magazine is of solid ashlar-work. The walls 1½ mètres (5 feet nearly) thick. The arch is parabolic; the height about 10 feet to the springing. There are two floors, the upper being supported in the centre by stout wooden pillars. The building is calculated to contain 70,000 kilos. (69 tons nearly) of powder.

There is a roadway round about it, about 7 feet wide, shut in by a brick wall plastered over, and covered with tiles. Its height is about 10 feet.

Near it is a guard-tent, with the usual "manteau d'armes."

No Abattoirs.—There are no abattoirs within the precincts of the camp. The meat is supplied by butchers from Mourmelon-le-Grand.

Appended to these notes is a list shewing the cost of the principal buildings, rate of wages, and price of materials.

Tents of two descriptions.—The tents in use are of two descriptions, the one elliptical, the other circular, bell-shaped. The former are issued for 12 men, but are made for 16 men each; the latter for 16 men, but are made for 20 men each. Among the tents that I visited, I in no case, however, saw more than 11 men in the bell-shaped tent, and frequently not more than 7 or 8.

Elliptical Tents.—The elliptical tents are supported on two poles and a cross-piece. They are not liked, and are abandoned in favour of the bell-shaped. They are now only issued to use them up. They are occupied by two regiments in the camp. Their size is 6 mètres by about 4 mètres.

Circular Tent.—The circular tent, 6 mètres in diameter, supported as usual on one pole, has a curtain round the bottom, capable of being lifted for the sake of ventilation, and an opening for ventilation at the top of the tent.

Ground Excavated within Tents.—In many cases the ground within the tent is excavated, to give greater height, the entrance being down one or two steps cut in the chalk; a slight surface-drain carrying off any rain. Frequently, also, a porch of canvas on rough poles covers the entrance.

Internal Arrangement of Tents.—The beds were straw palliasses, sometimes ranged close together, the men's clothing, &c., being on the opposite side of the tent;—sometimes two together, the clothing, &c., being between each two;—and sometimes each separate, with the clothing between. The accoutrements were hung round the pole. Although the weather was very hot, the tents that I entered were seldom unpleasantly close, and they were very neatly and cleanly kept.

Officers' Tents.—The officers' tents were circular, of the same size and shape as the men's. Colonels commanding regiments have two tents each; other officers one.

Cost of Tents.—The cost of each tent, of either description, is £12. A tent is considered to have lasted well if it stands two years. The cost of encamping men in tents, therefore, may be placed at 10s. per man for the four months the encampment lasts.

Plans of Encampment under Tents.—The Plans attached to this Report, shew in detail the tent encampment of a regiment of infantry of 3 battalions of 6 companies each, in circular tents, and of a regiment of cavalry of 4 squadrons, in circular tents.

General Description of Tent Encampment.—The men's tents are placed perpendicularly to the main road through the encampment. This road separates the men's tents from the kitchens and canteens, which are parallel to it. In rear of the latter are the tents of the Petit Etat-Major; then, of the Lieutenants; next, of the Captains; and, lastly, of the superior officers and Etat-Major. In rear, again, are the mess, and officers' stables; and, finally, the latrines.

"Manteaux d'Armes."—In front of the men's tents are small tents, covering the fire-arms, and called "manteaux d'armes."

Canteens and Kitchens of Wood.—The canteens and kitchens are of wood. There are two buildings to each battalion of infantry, each containing two kitchens and a canteen. They are 13 mètres long by 5 mètres wide (about 43 feet by 16·6 feet). In the Cavalry there are three buildings per regiment, each about 43 feet by 20 feet.

Mess House of Wood.—The mess establishment for each regiment is also of wood. It is placed in rear of the tents of the Colonel commanding. Its length is 40 mètres; its breadth, 6 mètres (about 131 feet by 20 feet).

Stables of Wood.—The stables are wooden sheds, open at the sides, which are generally hung with thick straw mats. They are not paved. The fitments are of wood. The horses are separated by bails, to which are attached small straw mats. They are 8 mètres long and 6 or 8 mètres wide (26 by 20 or 26 feet). There is one to each Infantry regiment, and two to each Cavalry, one being for sick horses.

Latrines of Wood.—The latrines are 11 mètres long by 2 mètres wide (36 feet by 6·6). Those for the men have no seats. The soil is received into ditches, which are emptied daily, or as required.

Weather-boarded Huts.—The above buildings are rough weather-boarded or slab huts, covered with planks and canvas pitched over, or with planks only.

Replacing Wood Huts.—In three or four instances the wooden mess-huts have been replaced by brick buildings similar to those in the hut encampment. One or two wooden stables with tiled roofs, and one or two latrines in brick, have also been erected.

General Officers and Chefs d'Etat-Major in Wood Huts.—General Officers commanding Brigades and Divisions encamped in tents, and their Chefs d'Etat-Major, have wooden huts. Their Staff occupy tents.

Canvas Verandah to Canteens and Mess.—A sort of wide verandah is commonly obtained outside the mess huts and canteens, by stretching canvas on rough poles. Under this, tables, forms, and chairs are placed for general use.

Price of Wood Huts.—The price per mètre carré of the wooden buildings averages 9 francs, or 7s. 4d., interior dimensions. Many were erected as required, without plans being first prepared.

Ground occupied by Tent Encampments.—The space occupied by a regiment of Infantry under circular tents, exclusive of the grass and gardens in which are the latrines, is 329 × 155 mètres, equal to about 12·6 acres, and including the grass and gardens 329 × 237 mètres, equal to about 19·2 acres.

Under elliptical tents the space occupied is 360 × 138 mètres, equal to 12·2 acres, and 360 × 219 mètres, equal to 19·4 acres.

The space occupied by a regiment of Cavalry* is 278 × 199 mètres, equal to about 13·6 acres, and 278 × 256 mètres, equal to 17·5 acres.

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* Of four squadrons. The horses are picketed by one foot to ropes fastened to pickets driven into the ground, in the streets, between the men's tents.

Artillery Encampment.—In front of the Artillery encampment are the guns and waggons in two lines.* Between these and the men's huts the horses are picketed by halters attached to ropes sustained on posts. The men's huts are in rows of 8 each, with an interval of about 6·6 feet between each two tents, and from 33 to 66 feet between the rows. In rear are 6 canteens and kitchens, and 3 rows of officers' tents, lining with those of the men. The mess hut and two stables are in rear of the officers' tents. Behind the two stables is another for sick horses, then a rear-guard in five tents, and lastly the latrines.

Engineer Camp.—The Engineers encamp by companies. Each company has 16 men's tents in four rows, and four officers' tents lining with those of the men; also a canteen and kitchen. Two extra wooden huts are used for tailors' and shoemakers' shops and for a store. There is also a guard-tent on the left front, and a hospital tent in rear on the left.

"Train des Equipages" and "Services Administratifs."—Two Companies of the "Train des Equipages" are in tents, and the men of the "Services Administratifs."

Use of Mules.—Mules are largely employed in the "Train des Equipages." They and the horses are picketed in the same manner as the Artillery horses.

Water Supply.—Water is supplied in the tent encampment by pumps and wells as in the hut barracks.

Watering Horses.—The horses are watered at the De Cheneu rivulet. In rear of the Engineer establishment, the water above an old mill has been dammed-up, and led underground by a pipe about 10 inches diameter, into a long water trough, laid along the border of the rivulet. At this the horses drink. Parallel to this, wells have been sunk and pumps fitted to insure a supply of water, should the rivulet, as has happened, run dry.

No Drainage.—There is no system of underground drainage. There are some surface water drains cut in the chalk.

Roads.—About 12 kilomètres ($7\frac{1}{2}$ miles) of road have been made 10 mètres (33 feet) wide, of which 4 mètres (13 feet) were macadamized. The cost was 15 francs (12s.) per mètre (3 feet 3·371 inches).

Lighting.—No lights are allowed in the tent encampment, except to the sous-officiers and cantinières. These must be in lanterns and extinguished at fixed hours. The latrines are lighted by lanterns.

In front of each Division is a "phare." There are no other external lights.

Fire.—In case of fire, the captain of the guard, who first becomes acquainted with it, warns first the Commanding Engineer, and then the superior Officer and General of Brigade on duty for the day. In urgent cases, he sounds the assembly on his own responsibility, which all the guards repeat. At this signal, 1 battalion of each regiment of Infantry, 3 companies of each battalion of Chasseurs-à-Pied, and 2 squadrons of each regiment of Cavalry, assemble in front of their several flags, and await orders.

Every division has a daily picquet of a company ready to march in case of fire or other emergency. This picquet is under the orders of the General of Brigade on duty for the day.

In addition to the three fire engines in the Engineers' yard, there are three at the Quartier Impérial, one at the theatre, two at the "Manutention," and one at the "Dépôt des Fourrages."

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* I was unable, while in camp, to obtain a plan of the Artillery encampment.

Telegraph.—Telegraphic communication is established. The instrument used is the Morse.

Practice Butts.—Butts have been erected both for Artillery and Infantry practice.

Maintenance of Camp.—The maintenance of the buildings in camp and contingent services are estimated at 30,000 francs (£1,200) only, yearly.

Relative Cost of Tents, Huts, and Barracks.—No details have been kept shewing the relative cost of encamping men for a certain number of years in tents, wooden huts, brick huts, and permanent barracks. The most expensive system of accommodation was said to be the tent, the next the wood hut, and then the brick hut; the least costly being permanent barracks.

The entire sum expended by the Engineer Department, including maintenance, to the end of the current year, was stated at from 4,000,000 francs (£160,000) to 3,600,000 francs (£140,000). In this are included 150,000 francs (£6,000) expended in searching for water.

The outside cost of the camp may, therefore, be stated at £380,000 including land, but exclusive of course of tents.*

B. H. MARTINDALE,
Captain, Royal Engineers.

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* Assuming the number of men encamped in tents since the establishment of the camp to have been 110,000, the expenditure for tents would be £55,000.

APPENDIX A.

LIST OF PLANS ACCOMPANYING NOTES.

1. Plan of part of the Map of France, shewing site of Camp and adjacent country.
2. Plan of Brick Hut Encampment, shewing present occupation.
3. Plan of an Encampment of a Regiment of Infantry in Circular Tents.
4. Ditto, ditto, of a Regiment of Cavalry in Circular Tents.
5. Plan shewing relative positions of the left of the Cavalry Encampment, the Engineer Establishment and Camp; 2nd. Ambulance, temporary Hospital, and Brick Hut Encampment.
6. Plan, &c., of a Soldiers' Hut, &c. } Drawn from Memoranda.
7. Plan, &c., of Huts for the "Petit Etat-Major," &c. } Drawn from Memoranda.
8. Plan, &c., of Officers' Quarters, and Mess Establishment, &c. } Drawn from Memoranda.

APPENDIX B.

LIST OF PRICES CONNECTED WITH HUT ENCAMPMENT, CHALONS-SUR-MARNE.

	Briques cuites. fr.	Briques crues. fr.	s. d.	s. d.	
Soldiers' Hut (interior dimensions)	42	45	33 7	36 0	Per mètre carré*
Petit Etat-Major	45	48	36 0	38 5	
Officers' Quarters	55	60	44 0	48 0	
General Officers' Quarters	70	75	56 0	60 0	

	fr.	£	
Soldiers' Hut, from	6,700 to 7,200	268 to 288	
Kitchen and Canteen	5,000	200	
Guard-House	4,500	180	
Lock-up (Regimental Prison)	4,500	180	
Latrine for one Battalion	2,800	112	
Stables for one Regiment	3,000	120	
Officers' Quarters, per hut	15,000	600	
Mess Hut	11,000	440	
Ambulance	30,000	1,200	
Engineer Establishment	51,000	2,040	
Forage Store	102,000	4,080	
Store "d'Habillement et Campement"	117,000	4,680	
Hospital, 2 stories, for 100 patients	115,000	4,600	
Cost per man, everything included	200	8	
By Battalion	200,000	8,000	
By Regiment	400,000	16,000	
By Division, including accommodation, as stated in report	2,000,000	80,000	outside price.
	fr.	s. d. s. d.	
Wages of a carpenter, smith, tinsmith, or joiner, per day of 10 hours' actual work; if less work, less pay	5 to 6	4 0 to 4 10	
Slater, glazier, or painter	5	4 0	
Mason or bricklayer	4½ to 5	3 7 to 4 0	
	centimes.	d. d.	
Military labour (10 hours' work) Line	25 to 60	2½ to 6	
,, ,, Sappers	40 to 65	4 to 6	

May reach 1 franc by task-work, or day, if employed in water.

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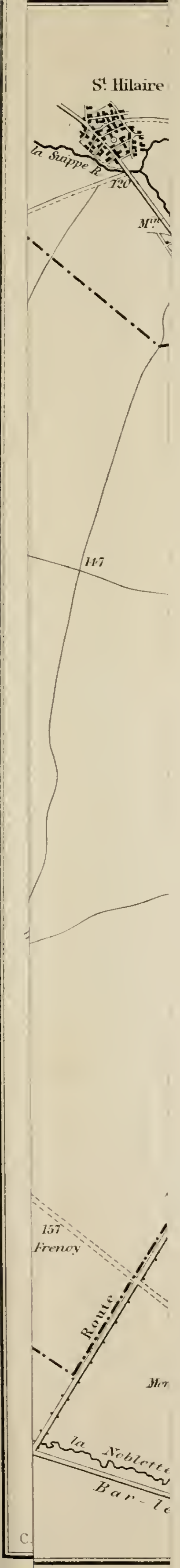
* The square yard is 0·836 of a square mètre.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la Suippe R.
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Mlin
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157
Frenoy
Route
Mor
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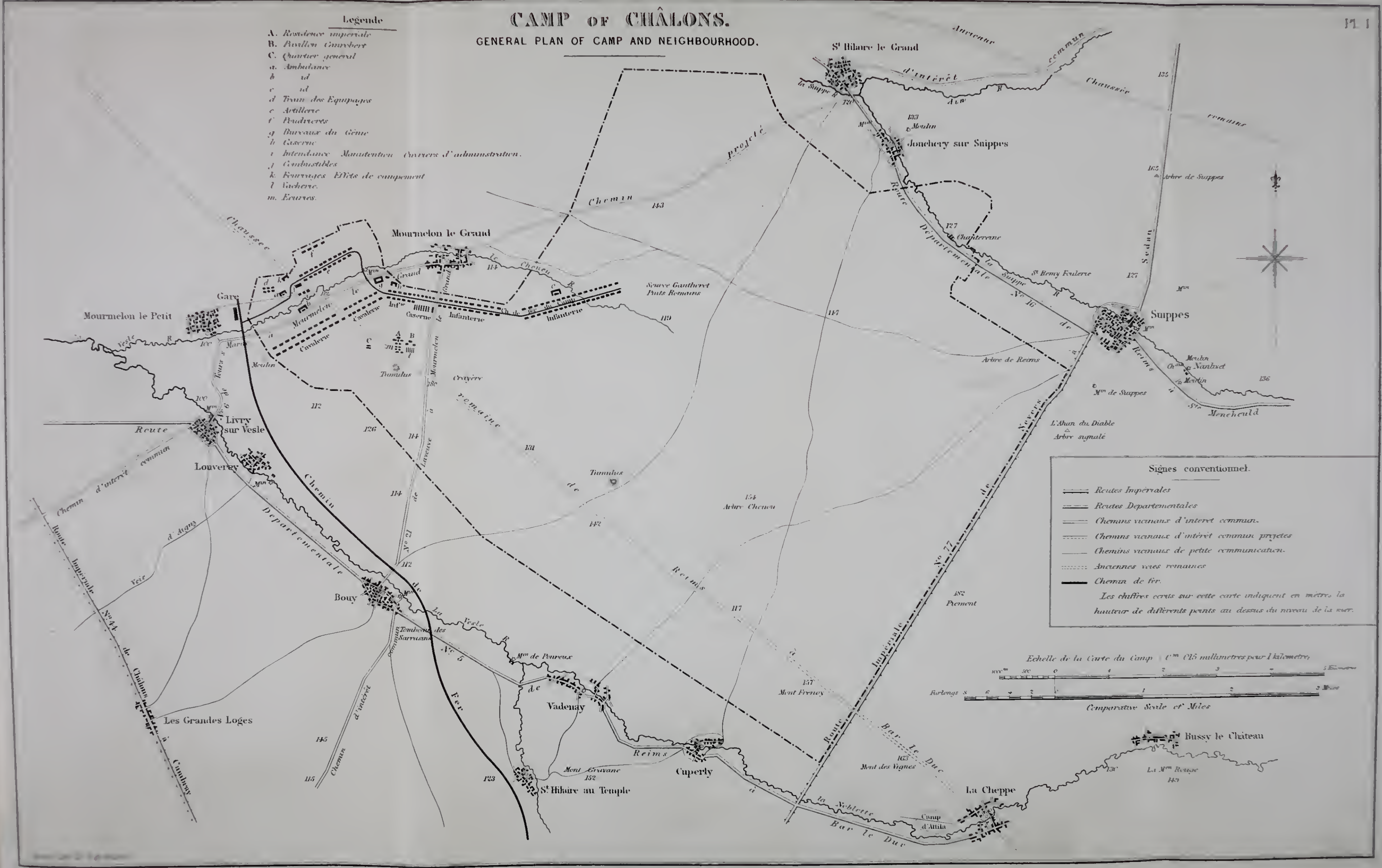
CAMP OF CHÂLONS.

GENERAL PLAN OF CAMP AND NEIGHBOURHOOD.



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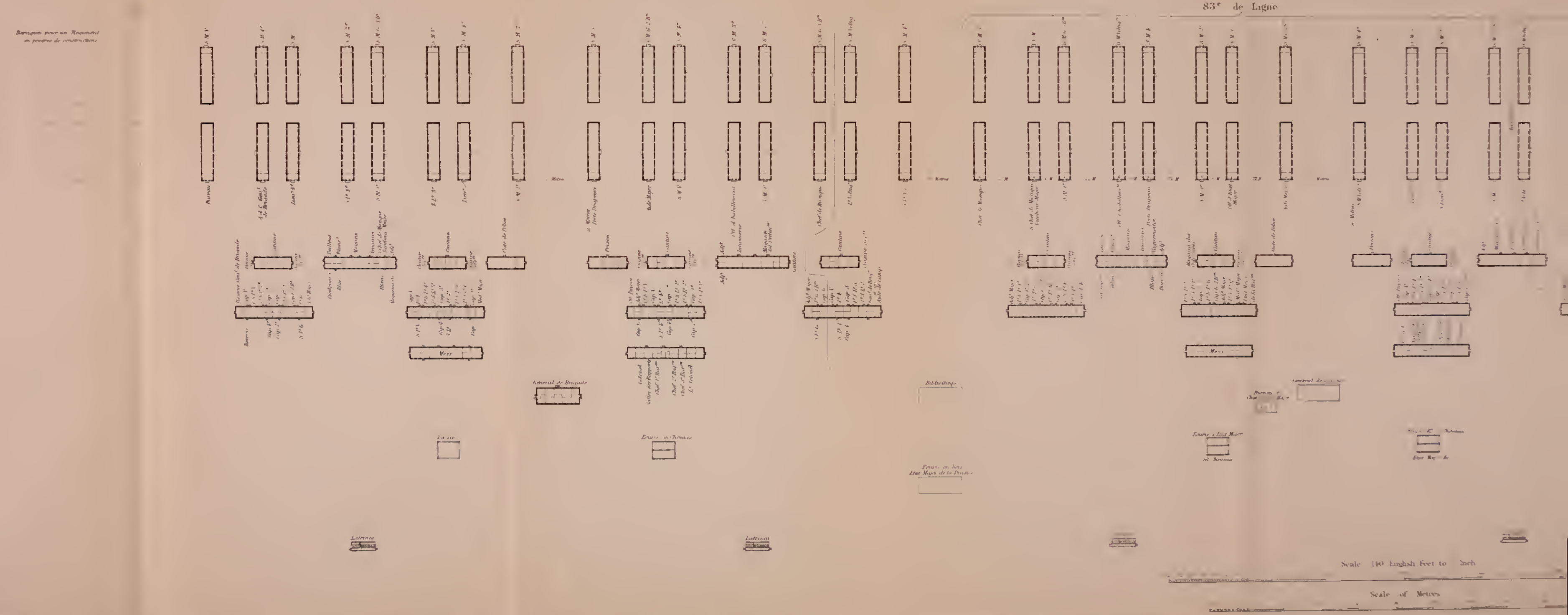
PLAN OF THE HUT ENCAMPMENT



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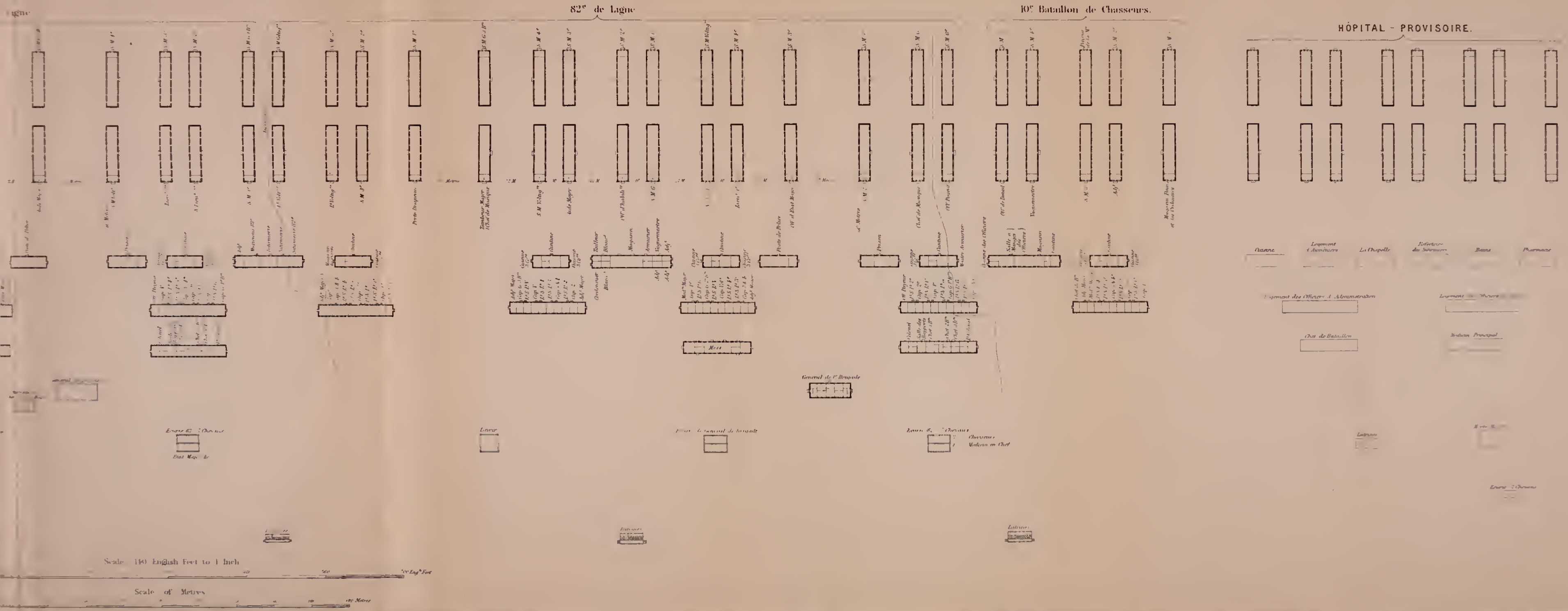
LAN OF THE HUT ENCAMPMENT.



Pl. III.

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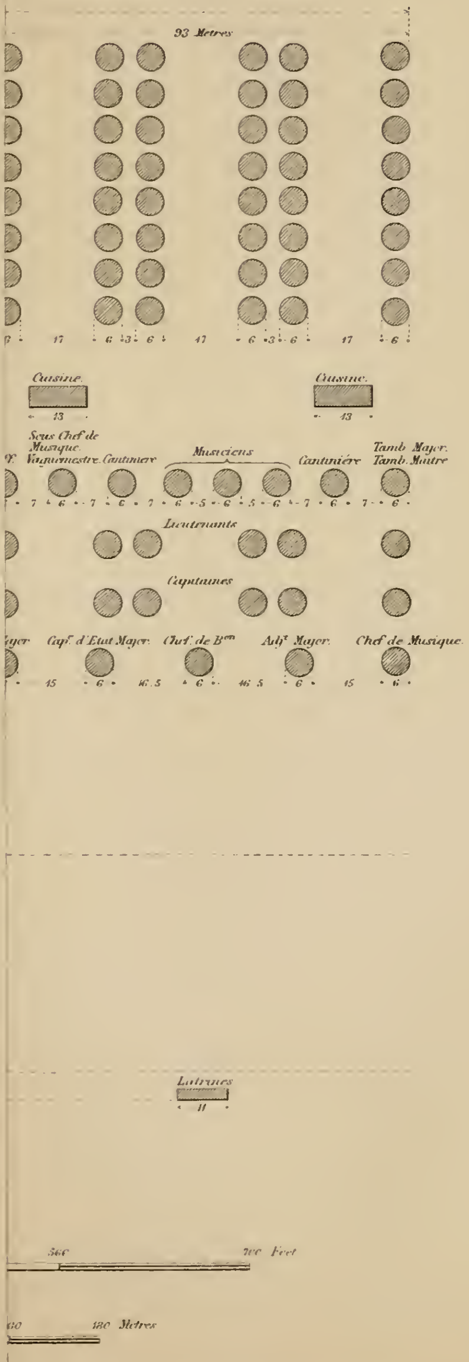

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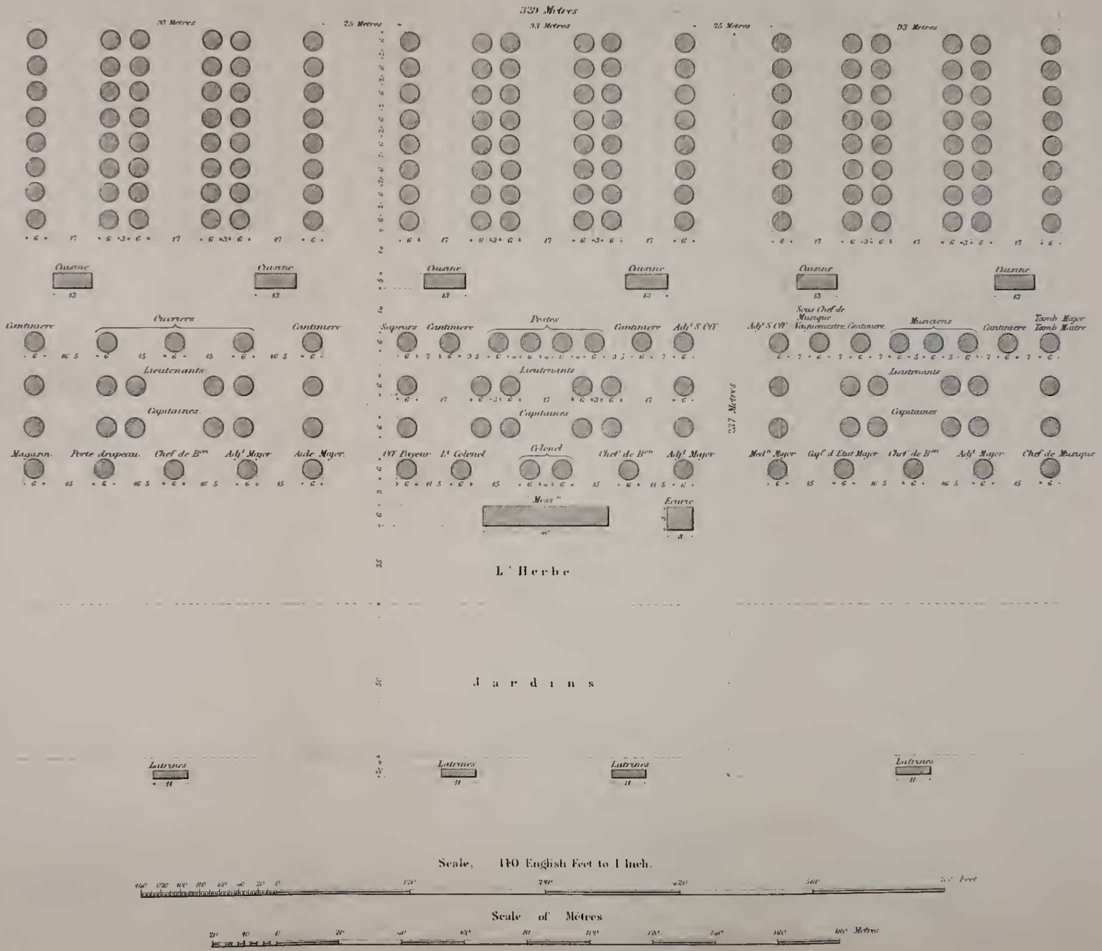
CAMP OF CHÂLONS.

2ND REGIMENT, 2ND BRIGADE, 1ST DIVISION OF INFANTRY. (TO THE RIGHT OF THE ARTILLERY)



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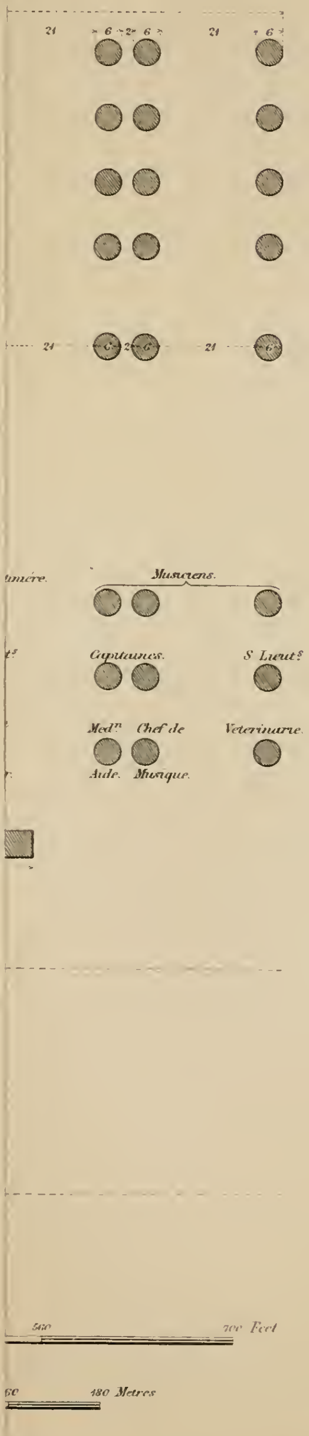
Pl. IV

R SQUADRONS.



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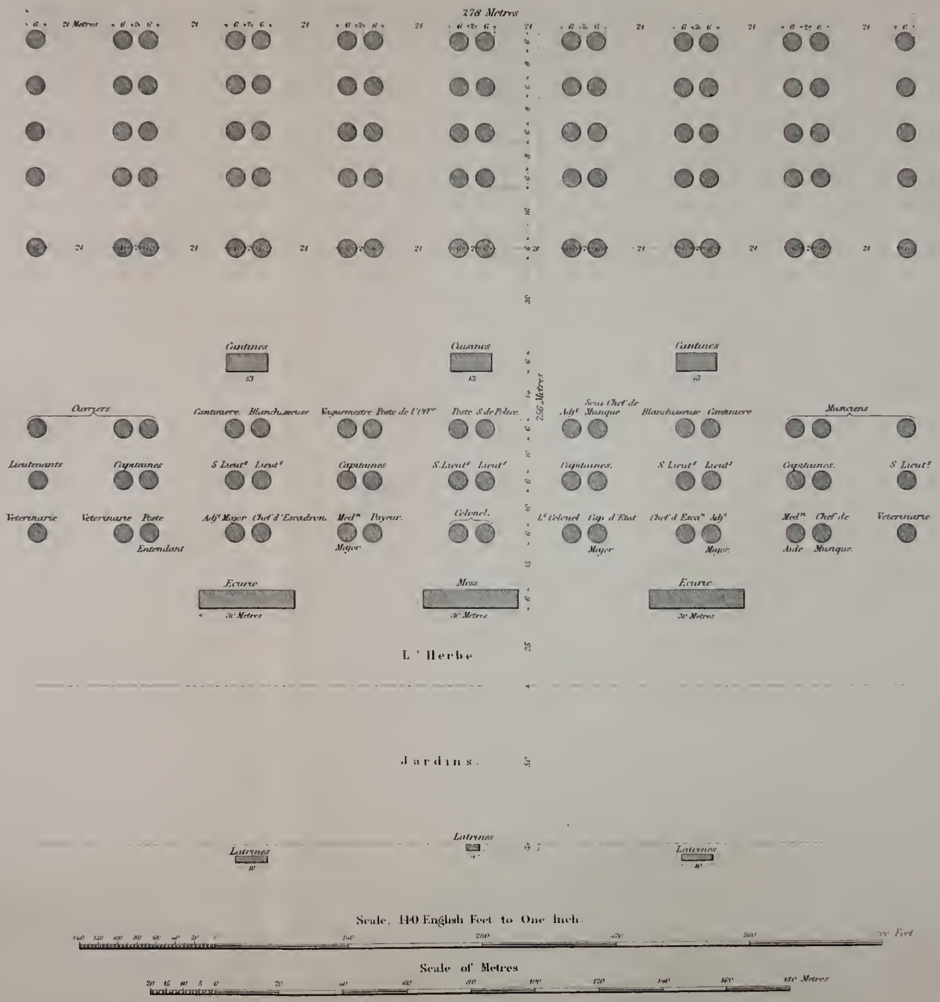
CAMP OF CHÂLONS.

TENT ENCAMPMENT OF A REGIMENT OF CAVALRY OF FOUR SQUADRONS.



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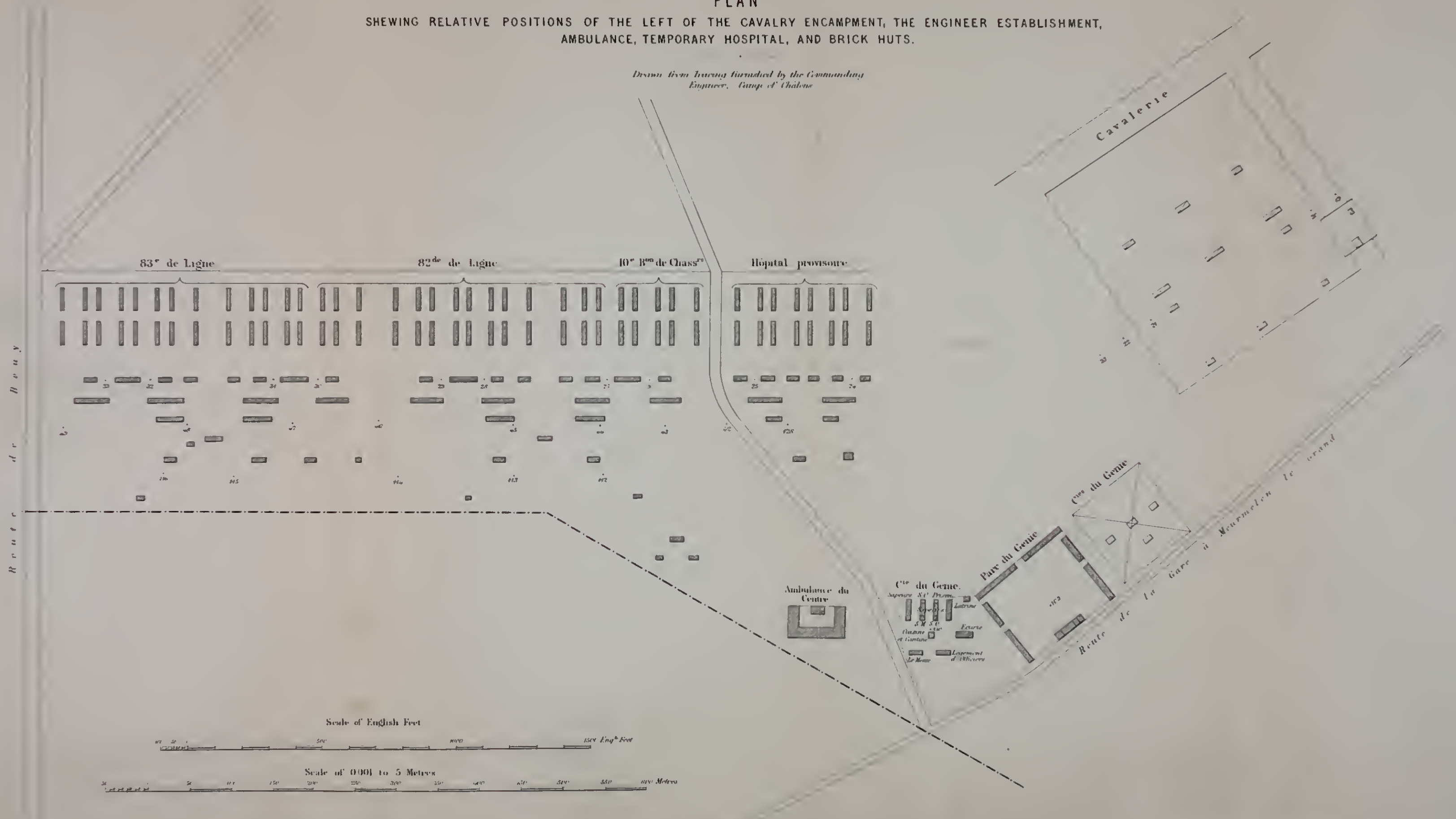
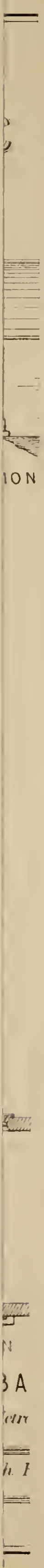
CAMP OF CHÂLONS.

PLAN

SHEWING RELATIVE POSITIONS OF THE LEFT OF THE CAVALRY ENCAMPMENT, THE ENGINEER ESTABLISHMENT,
AMBULANCE, TEMPORARY HOSPITAL, AND BRICK HUTS.

Drawn from tracing furnished by the Commanding Engineer, Camp of Châlons

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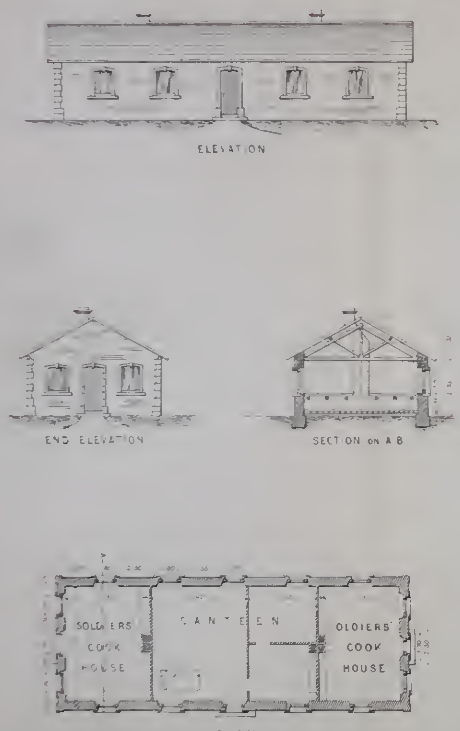
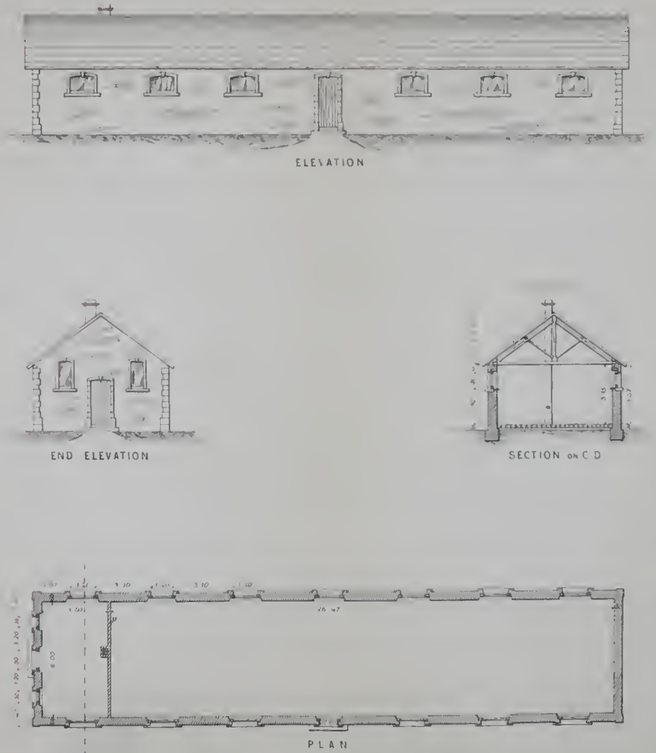
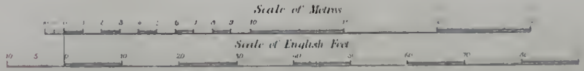
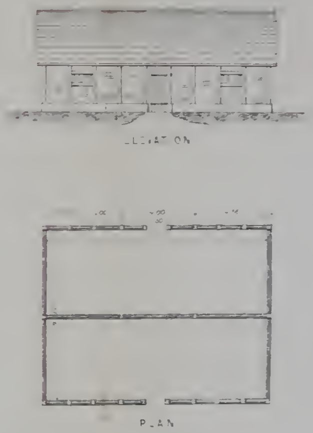


CANTEEN & SOLDIERS' COOK HOUSES

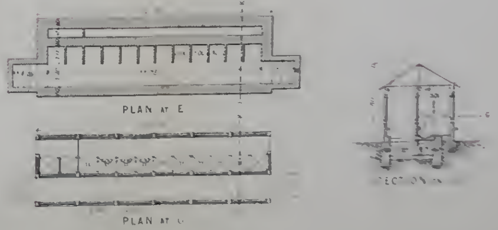


SOLDIERS' BARRACKS



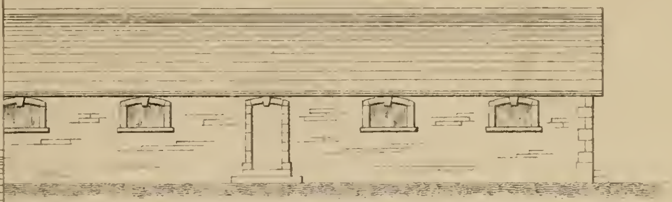


STAFF STABLE
16 HORSES

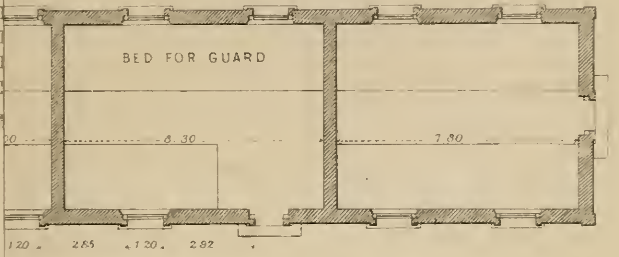


SOLDIERS' LATRINES

Pl. VII.



FRONT ELEVATION



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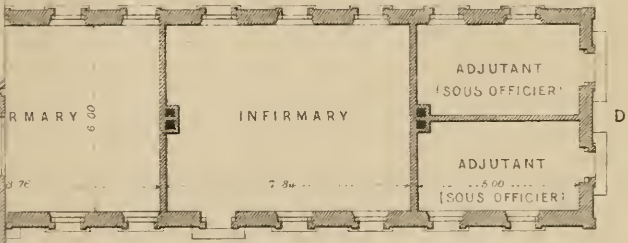
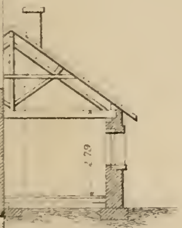


Y "PETIT ETAT MAJOR" 1ST BATTALION



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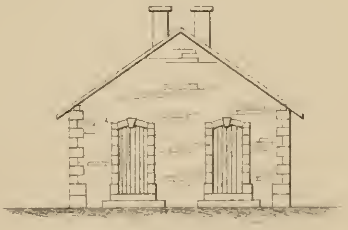

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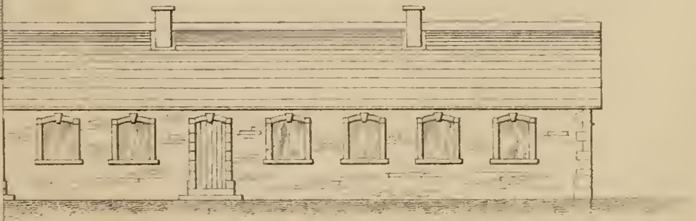

EVATION

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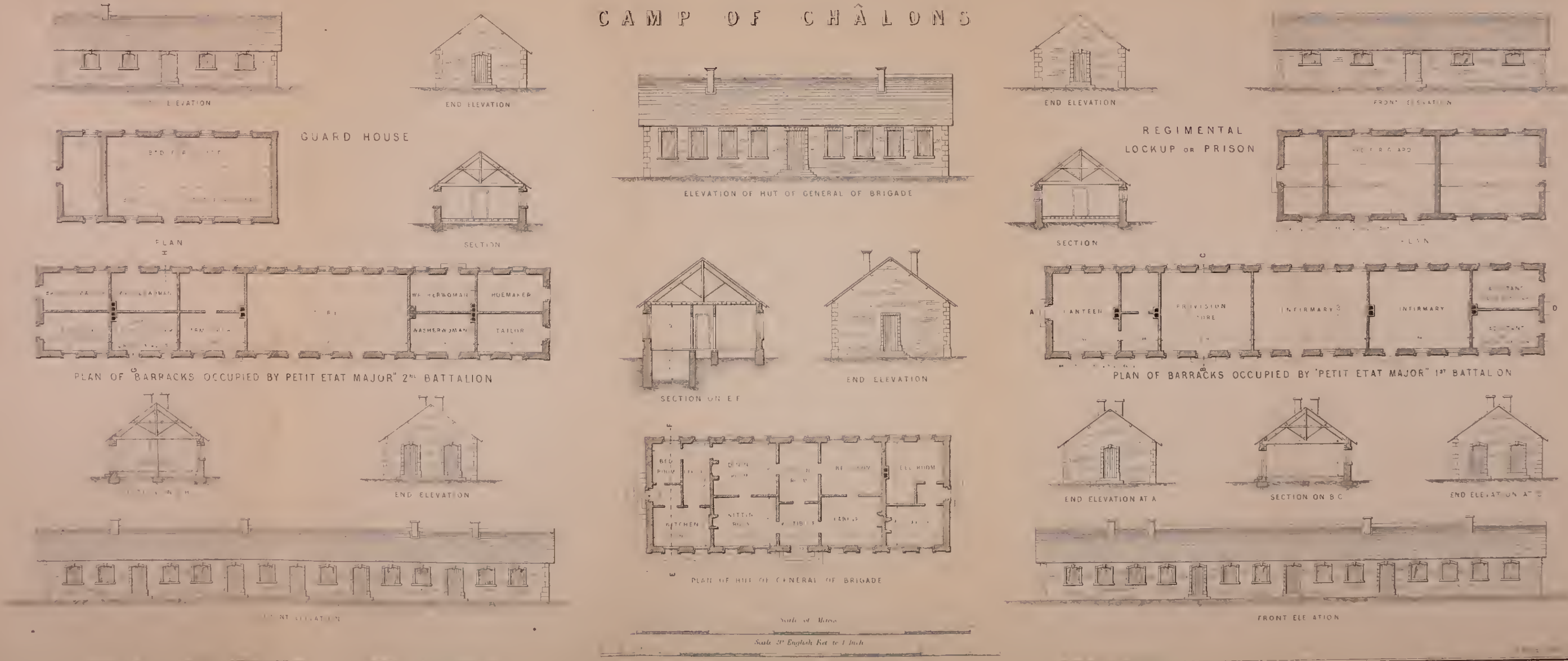
Pl VII

CAMP OF CHÂLONS



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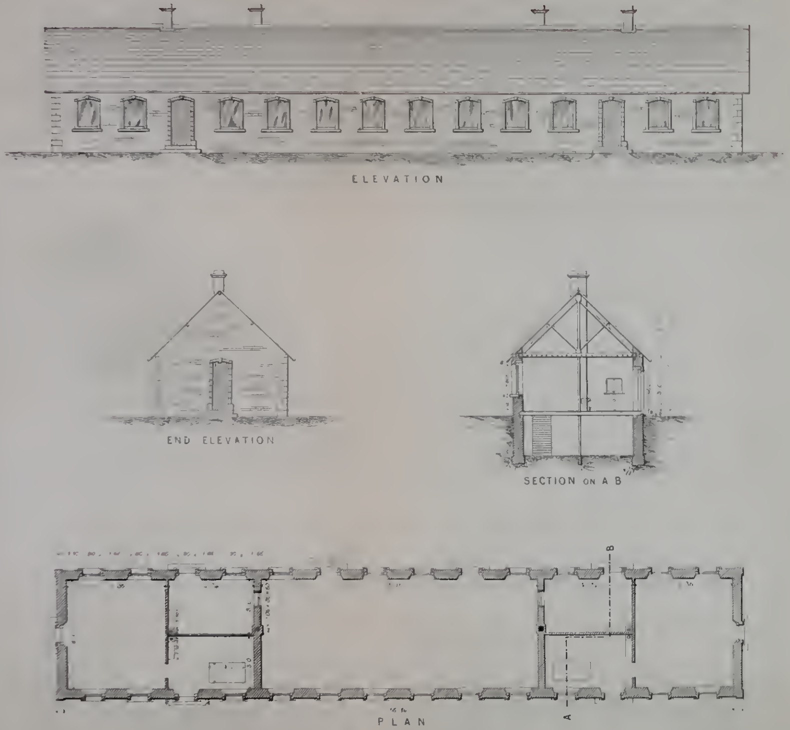
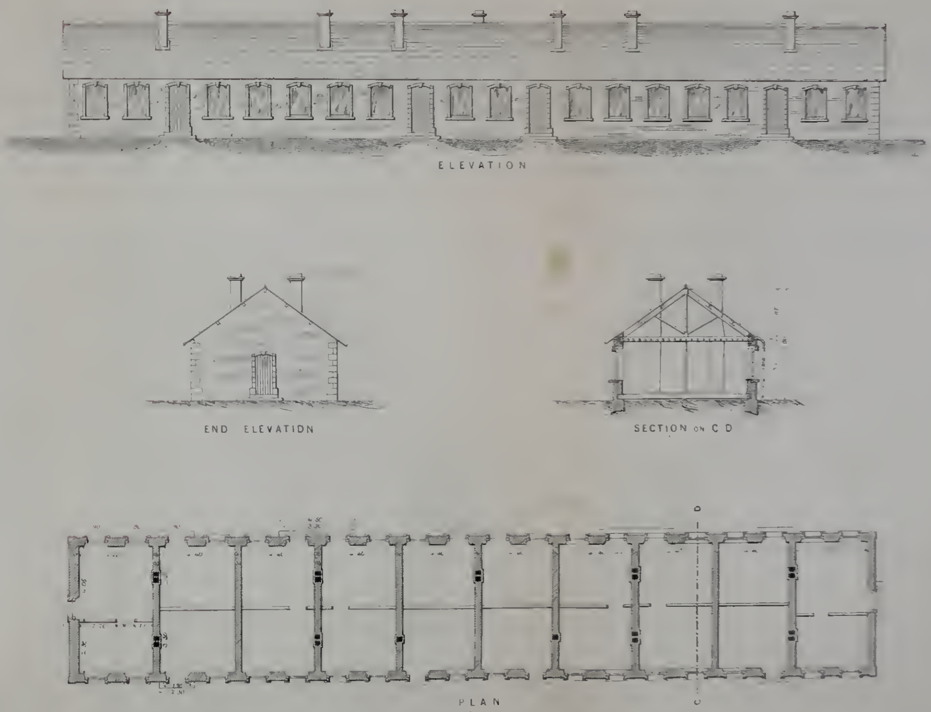
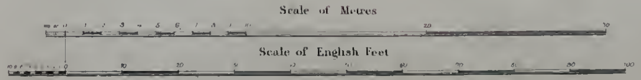


OFFICERS' MESS ROOM



OFFICERS' BARRACKS



	francs.		s.	d.		s.	d.
Masonry—foundations	18	Per mètre cubique*				14	5
„ above ground	20					16	0
Brickwork—cuites	50					40	0
„ crues	9					7	3
"Briques cuites," per 1,000	46 to 50		36	10	to	40	0
"Briques crues," „	10					8	0
Round timber, per mètre cub.	45					36	0
Squared (according to length)	65 to 70		52	0	to	56	0
Floor planks ("sapin," 1″ thick) per mètre carré	1·50					1	2
Lime, per mêtre cubique	22					17	7
Cement de Vassy, per 100 kilos. = 1·97 cwt.	15					12	0
Sand, found on the spot							
Slates, per 1,000	28 to 32		22	5	to	25	7
Rubble stone, per mètre cubique	10					8	0
Painting, including paint, per mètre carré	1·10						10
Glass stopped do.	55					44	0
Ashlar stone door steps, set, per mètre cubique	150					120	0
Ashlar stone door-jambs	110					88	0
„ window sills	83					66	5
Wooden buildings in Tent Encampment, per mètre carré	9					7	4
Tent	300					240	0

* Mètre cubique = 35·31658 English cubic feet.

PAPER VIII.

MEMORANDA ON THE CONSTRUCTION AND APPLICATION OF VAULTED REVETMENTS.

By COLONEL NELSON, R.E.

The following paper, with exception of paragraphs 52-57 just added, was sent to Germany, in hopes of obtaining the friendly but frank criticisms of some officers of great experience, especially as regards Vaulted Revetments. By mistake in the delivery of the parcel this purpose was frustrated; but I have, nevertheless, obtained from the same quarter a series of remarks which give the views at present prevalent in the N., N.W., and W. of Germany, in opposition to those quoted in paragraphs 26, 36, &c., which last may be referred to the school of Von Aster.

These remarks will be embodied in Part II.; and we are happy in thus having the objections to Vaulted Escarps completely exhausted.

With the most respectful deference to the opinions thus expressed, I must, however, state that I am unable to adopt them, either in whole or part, as will be seen by the observations placed in opposite column, seriatim.

This statement may be of as much service to my honoured "Herrn Cameraden," as their ready and courteous compliance with my requests may well prove to our own officers.

PART I.

NOTHING CAN DO EVERYTHING!

1.—To discover the Universal Menstruum—the Philosopher's Stone—the Elixir of Life—Perpetual Motion, &c., &c., &c., were once favourite pursuits; from those times we seem to have inherited a lingering tendency towards an unexpressed hope that a *perfect* system of fortification may yet be discovered; and we are thus instinctively and pettishly very apt to reject at once as useless, any project that does not achieve "Everything."

2.—With thus much on the reasonableness of expecting perfection and infallibility, even in the arrangement of brick and mortar, it may be observed that although Carnôt's principle failed in 1823-24 at Woolwich (after three days' battering, under every advantageous circumstance to the besieger, and without the hindrance of a single shot or sally from the besieged), yet the difficulty in thus destroying his detached escarp *behind* a counterguard, was a compliment indeed, of a high caste, and of a very practical character. We may yet hear of this system again, as well as of the Vertical Fire* of this first-rate Engineer.

3.—We have to thank Colonel Ross for his good paper in our last volume, detailing the Artillery practice at Juliers, 1860; the point of interest therein, as far as we are now concerned, is the resistance made by the Revêtement-en-Décharge of the bastion, notwithstanding its having been battered at the distance of a stone's throw, and despite the very defective construction, which marks it as one of the earlier attempts at this sort of escarp. Though neither "perfect nor infallible," it affords an excellent illustration of the difficulty in bringing down a vault when seen end-on; and if this needs confirmation, we shall find something to that effect in the paper, for which we are indebted to Sir John Burgoyne, on the effect of rifled ordnance on the Martello Tower at Eastbourne (Figs. 3, 4, 5,) even though that *annular* arch was necessarily battered sidewise.

4.—To proceed, then, with the more immediate subject of this paper on Vaulted Revetments.

5.—There has hitherto been much confusion in the terminology of this matter, which should be disposed of prior to entering upon it; the following, perhaps others, have been used in designation :—

1st. Revêtemens-en-Décharge.
2nd. Breschebogen.†
3rd. Rückwärts offene Decharge-Casematen.
4th. Rückwärts geschlossene Decharge-Casematen }
or
5th. Decharge-Casematen mit Rückwand. }
6th. Counterarched Revetments. Erdgürten.

6.—Of the above, No. 1 is the most correct, in so far as it does not enter into those details of varied construction which are so loosely given in Nos. 2, 3, 4, 5. As to No. 6, it is altogether wrong; a counter*arch* is what is shown at *v* Figs. 1, 4,—simply an inverted arch, in the body of a wall, to prevent unequal settlement. Even counter*vaults* would have been incorrect, for they also are inverted, and are used to secure uniformity of settlement under whole buildings in treacherous soils; as in the case of the detached storehouses in Sheerness Dockyard (built by Rennie prior to 1826), each of which is a sort of island, almost floating on the quicksands some feet below the surface; the cost of the foundations amounting to about one-third of the expense of the whole building. Another example of "Countervault" is shewn in the section of the Eastbourne Tower (Fig. 8, see above-mentioned paper), as an annular invert.

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* See "Fire Vertical" Aide Memoire. Rarely has a principle been so cruelly burked by special pleading—pseudo-scientific and otherwise,—as this has been!

† Bogen, and Bug the bow of a ship,—both (from biegen, *bog*, gebogen) evidently identical with the Cornish (Celtic) Voug or cave. B = V.

7.—In the following observations, only one term, will be used throughout, *i.e.*, *Vaulted Revetment*, as I consider it to be, to English minds, the most accurate, the simplest, and the most expressive; "closed in rear," or "open in rear," can be added when necessary.

8.—These vaulted revetments may be dealt with in reference to the following, though doubtless there are other applications of the principle; by and bye it will be probably still more in vogue.

1st. Resistance to battery.
2nd. Resistance to the explosive action of frost.
3rd. Resistance to pressure of backing; especially in certain kinds of expansive clay.
4th. Resistance to pressure of backing behind, in connection with quicksands behind or beneath; with or without countervaults.

9.—All that will be at present attempted is to call more especial attention to No. 1, with no further reference to detail than is necessary for general reasoning.

10.—I believe that I am the first Engineer who has proposed No. 2; observing that by "explosive" is meant the instantaneous and well nigh irresistible action which bursts the 10-inch shell when filled with water and properly secured; and which is everywhere in our northern colonies recognised as a cause of so much anxiety whilst building massive works with earth backings.

*Resistance to Battery.**

11.—The recent improvements in artillery have thrown a heavy weight into the scales, whilst weighing the relations of Attack and Defence. The introduction of enfilading fire alone destroyed all "equation" here; but the preponderance of Attack has been of late vastly increased by the introduction of the "Armstrong" principle,—to say nothing of the "Minie" rifle.

13.—The information afforded by the brief, but valuable, paper in Vol. X, giving the results and detail of the breaching of the Eastbourne Tower—taken in connection with what may be learned from Shoeburyness as to the fate of 10-inch-square wrought-iron beam revetments—all give plain notice to quit our too long maintained hold on massive revetments; and it is thus that attention is now invited to the vaulted sort, not only in meeting pressure from backing, in both escarps and counterscarps, but in reference to resisting battery in escarp only; the one being purely static in character, the other involving a mixture of static and dynamic considerations: we are too apt to lose sight of the latter, especially as regards the effect of vertical fire; as if the piers of a bomb-proof magazine, &c., were sufficiently strong when they only maintain the thrust of the arch in equilibrio; the blow, as well as the explosion of a heavy shell, tends notably to increase the "wedge" action of the vault in throwing over, or otherwise damaging, the piers.

14.—Although it is quite possible to conceive a better arrangement of wrought iron than was used in the above mentioned experiments at Shoeburyness, such perhaps as that now suggested in Fig. 13, it would appear that, as regards massive revetments, there may be for some time yet, a sort of auction for the highest bid (as a brother officer calls it) between mass in escarps and momentum in shot, even to the introduction of the x^n Pounder; still, the warning note and knell of the "massive" has been plainly sounded. Must it pass unheeded? Is not its existence a doomed one?

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* Occasional references to resistance to backing have been unavoidable.

15.—The objection to the transport of such heavy ordnance in sieges, promises to disappear before the carriage lately introduced by Lieutenant-Colonel Clerk, R.A., Superintendent Royal Carriage Department, by which the 10-inch and 13-inch mortars are now added satisfactorily to the siege train.

16.—To revert, then, to the general consideration of the vaulted revetments.

17.—The earliest date of these that I have as yet been able to discover, is given by Colonel Ross (on the authority of Captain Giese, of the Prussian Engineers), as about 1550, in the main escarp of Juliers; and this does not look like a first attempt. They are further to be seen in Coehorn's first system (1685), in a far more complicated form, though but in one tier only, under circumstances that would probably have called for countervaults, properly so called. See Figs. 10, 11, and Appendix A.

18.—In Mandar's Plate V, Fig. 114, they are shewn in both escarp and counterscarp in three stories, and one, respectively; but nothing is said of the Engineer or date, nor of the intermediate steps of progress, except perhaps Fig. 112. The few observations in his text (pp. 451, 452) are but little to the purpose; there is no *necessity* for the numerous openings in the piers on which he seems to rest his objections; such as are indispensable may (and should) always be counterarched. He says nothing of the almost impracticability of building the upper tiers without foundations reaching down to the level of those on the ground-floor; and, it is this very inattention to equality and uniformity of settlement, *in the whole mass bodily*, that has possibly brought this principle into undeserved neglect. Very significant notice of the effect of carelessness on this point is given by Von Wurmb in his excellent Lehrbuch der Kriegs-Baukunst.

19.—Towards the close of the last century, however, the vaulted revetment seems to have been again used; but as much perhaps to meet the difficulties in the soil as for any other purpose.

20.—In the latter case, when it is not intended to use the vaults as casemates (for temporary barracks, hospitals, stores, &c., and during a siege) the rear is left open, as at MP, Figs. 1, 4; and the earth of the backing or rampart finds out its own slope inside the vault. It is probable that the constant settlement of the earth thus left to itself, will for some time disturb the parapets and terrepleins immediately over the rear; though this may be, in some degree prevented by layers of brushwood, or hurdles, interspersed liberally through the more advanced portions of the sloping mass, with or without the assistance of ramming the earth in layers.

21.—When, however, it is intended to utilize these vaults, they are closed in rear, sometimes by a flat wall, sometimes by one presenting an arch (see Figs. 3, 6) to the pressure in rear,* or at others by one with the interior arched, and the back flat. It does not seem to be necessary that these back arches should be built in voussoirs like the vaults above. Attention will also now be necessary to arrangements for light and ventilation, the openings being, as much as possible, convertible to defensible purposes as loopholes, smokeholes, possibly embrasures.

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* See also Fig. 8 of Colonel Ross's paper, Vol. X.

22.—In either case, utilized or not, there should be communications, *V V*, Figs. 1, 3, 4, 6, all through each range, connecting also with the rear of the rampart from time to time.

23.—In both cases, the greatest care must be taken to provide vent for any water that may accumulate, by weepers, *U U*, Figs. 1, 2, 4, 5. When these pass through the back walls the water should be led to the front by gutters sunk in the floors of the casemate.

24.—The question of the vaults passing entirely through the front wall, or stopping at about a foot short of the face (Figs. 1, 3, 9), has been one of much discussion.

25.—It is argued that the ends of the vaults should be concealed from the enemy; it does not, however, appear that this is of any great moment—either the escarp is exposed, or it is not; if *not* thus seen, the objection is irrelevant; if seen at all, the first few trial rounds of the enemy will shew him at once where they are; if there be embrasures in naked scarps, he will probably have other notice, rendering the " trial rounds " unnecessary. The foot of the exterior slope of the parapet will soon follow the slight but unsupported portion of the escarp, used in masking the vault, into the ditch below.

26.—In the Austrian school, the ends are concealed; whilst the Prussians, as at Coblentz and Ehrenbreitstein, send them boldly through the fully exposed escarps. Engineers who have visited these places will remember the complete example of this given in " Das Ungenannte," at the South-East corner of Ehrenbreitstein, looking up the Mühle-Thal.

27.—The difficulty of breaching these vaulted escarps would probably be very great, even if exposed; what if they be covered by Carnôt's counterguards? As regards resistance to pressure in rear, nothing will now be said: the application of countervaults is only an extension of the principle where required by peculiarities in the soil beneath, or behind and beneath.

28.—The relative costs of the massive and vaulted systems may always be equated by so regulating the number of tiers, and the dimensions in detail of the vaults and piers of the latter, that the estimates for both shall be equal in amount; and in these computations it may be assumed, as the result of much experience, that a depth of 4 feet in firm gravelly soil is sufficient for foundations; 3 feet for the thickness of the pier (with a 6-inch offset on each side below), and from 1 foot 6 inches to 2 feet thickness of vault, according to the nature of the material.

29.—The working out of these estimates, varying at all points with the quantity and quality of the several materials, with the labour, transport, and other questions of time and place, is left to the zeal and intelligence of the Projector.

30.—It may here be observed that though my own computations for the dimensions of the *equivalent* vaulted escarps in Figs. 1-6 are *tolerably* correct, yet it will be safer to consider them as approximate only; throughout, only *cubic content* is regarded, without reference to the expense of the different materials.

The following paragraphs, 31-42, and the plates to which they refer, give effectively the substance of this paper, which is little more than suggestive in character; it being intended rather to set others in action than to furnish essays on such subject as are noticed in par. 8.

31.—The illustrations offered in Figs. 1-6 have been so arranged as to admit freely of general comparison, rather than as shewing the average modern practice, especially as regards height of escarp;—for this last, in the Austrian school, see perhaps Fig. 9—as there are many minor differences in construction, partly arriving from the especial requirements of the work as regards function and character, partly from the nature of the local resources, and partly from the opinion of the Engineer.

32.—In Figs. 1-6, a bay of the massive escarp (32 feet high, combining pretty nearly the general practice of Vauban and Cormontaingne) has been selected for comparison with a bay of the vaulted revetment of the same height. The Prussians and Austrians differ at present much as to this last dimension; it is a point that will always be one of the first to vary with the views and circumstances of the times. The Great Duke, however, ordered the escarps at Bermuda to be 35 feet in height, to be secure against escalade; he probably remembered his successes at Badajoz. As there is nothing in the "vaulted" principle to interfere with section, the height of 32 feet has been assumed for convenience. The main escarp at Juliers was 32 feet 6 inches in height *above the water*, and was apparently in two tiers of vaults (the photographed sheet says three) from that level upwards; the total height of the wall being about 40 feet.

33.—The massive revetment lies in 18-feet bays; the vaulted bays generally at present, as by Von Wurmb, about 15 feet; at Juliers, 16 feet, more than three centuries ago; hence $\frac{15}{18}$ of the former only is brought into account, as run of escarp, for comparison.

34.—The same references have been preserved as much as possible in the Plate.

Explanation of Figures.

35.—Plate I, Figs. 1, 2, 3.—Comparison of massive and vaulted escarps on the same footing as to height and cubic content; the former with its counterfort are shewn in strong dotted lines, $A\ g\ h\ j\ i$, Fig. 1, the latter by $A\ B\ K\ L\ M\ P$, either closed in rear ($S\ t\ u$ or S, Fig. 1, 3), or open in rear as at $M\ P$ or M; in either case offering a serious obstacle to assault, whether breached by shot or shell. The question whether the lower vault should go through the back wall, as at t, is open, too, for consideration as regards uniformity of settlement; and, to a certain extent, expense. The parapet in both cases is modernized to 25 feet in thickness.

36.—Plate I., Figs. 4, 5, 6.—As well as my memory and sketches inform me, the escarps at Coblenz and Ehrenbreitstein are vertical, or nearly so. The Austrians seem to prefer a slope of $\frac{1}{8}$, with an average thickness, under favourable circumstances, of 3 feet at top. Assuming that the piers and vaults provide entirely for stability against pressure in rear, it is not very clear why the escarps are left so thick; they cannot pretend to resist battery, and are probably more than strong enough to resist the splinters of the largest shells; hence, assuming 2 feet as sufficient for this last, *if* this be correct, a thinner escarp allows the alternative of either longer vaults at the same cost, or shorter ones with an obvious saving.

37.—These figures exhibit a comparison between the same massive escarp, as in Fig. 1, 2, and 3, and a vaulted one with an escarp, though only two feet in thickness.

38.—Plate II., Figs. 7, 8.—Here the same thin escarp is under comparison with the preceding only, omitting all further reference to the massive. Three tiers are shewn here with, of course, a reduced length in reference to equal cubic content; there is, however, full scope for the closed ends, if necessary.

39.—In all such constructions, whether in two or more tiers, it may be borne in mind that if resistance to pressure of backing *only* is intended, then the upper vaults may be shorter than the lower ones, as shewn by the dotted lines *E F G H I J*, Fig. 7; but, if resistance to battery also is contemplated, then the vaults should be as deep as may be, and equally so throughout, as observed in par. 18: unless under exceptional circumstances of very rare occurrence, as to command of time, character of foundation, and material, the foundations of the upper stages must all come down to the level of that of the ground floor; in ordinary cases it is impossible to make the upper chambers longer than those below without ruinous settlements.

40.—Plate II., Fig. 9.—As noticed in par. 31, there are many varieties in the details of these revetments; but this figure seems to embody what in the Austrian school is most in vogue under ordinary circumstances. Attention is called to the height of the exterior slope of the parapet; all very well if the 27-feet escarp were secure from escalade, but it is not.

41.—In this, and Figs. 1 and 2, is a peculiarity in the dos d'ânes that is probably Austrian; the *ridges* slope about 1 in 10 to the rear. The merits are not very obvious, and it has the defect of lowering the level of the vault on the face of the escarp.

42.—Plate II, Figs. 10, 11.—Application of this principle by Cochorn in his first system, as given by Bousmard. See abstract from his "Essai de Fortification," Liv. I., chap. 10., appended.

Fig. 12.—Arrangement where the piers may not be crippled by the entry of the vaults, as at *a b c*, Fig. 8, &c.

Fig. 13.—Project of wrought iron revetment, as seen in plan, for special cases. The voussoirs to be of any such convenient scantling, and requisite length, as shall be determined by experiment.

43.—The main object of this paper having been now fulfilled in bringing this subject, as it is hoped, in a concise and convenient form for *general consideration* before the corps, it is left for the individual study of its several members as regards detail, application, or improvement. A few words only will be added as regards certain constructional points.

44.—The thickness of the vault in the preceding figures is sometimes given at 1 foot 6 inches, sometimes at 2 feet; the former refers to brick alone; but it is not proposed to restrict ourselves to the use of this. It is hoped that much economy will result from the use of local materials not hitherto very usually, if at all, so rendered available; such as the rough flags of slabs in districts of slate and sandstone just as they rise in quarry, and untrimmed beyond the clip of the mason's knobbling-hammer or stone-axe, just to fit to soffit, or to pack properly.

Lime stones, especially those of the secondary formations, often give a satisfactory flat bedded rubble quite suited to this sort of work.

45.—I have used rough slate at Devonport with perfect success in small 9-feet arches. Certain experiments there, in which I endeavoured to test the local practicability of such an escarp as *X Y Z*, Fig. 8,* in the same material, gave full encouragement, even if I had not seen something like it at Deutz; and very lately found good warrant for it in the ruins of the old casemates at Louisbourg, in Nova Scotia, where rough sandstone flags are seen to give good firm (though rough) work even when dry, and which would have been excellent, had mortar been used.

46.—In all vaults and piers the *best* hydraulic lime should be used; the escarp and back walls may be in common mortar, and hence should be built at leisure after the preceding; the piers must be of the *strongest* masonry.

47.—In all formations the vaults may be formed, it is conceived, in voussoirs of *sound* concrete; but the economy of this depends entirely on local circumstances.

48.—All these vaults (Figs. 2, 5, 8) enter the pier as whole skewbacks, which will cripple the said piers severely if battery is to be resisted; where pressure of backing only is in question, it is, perhaps, of little consequence. The practice shewn at *p*, Fig. 5, can only be advisedly done with brick, and its merits are on the whole equivocal, especially in case of battery, either from vertical or other fire.

49.—To avoid this crippling of the piers, the construction shewn in Plate II, Fig. 12, may be adopted; but this will give a width of 16 feet to each bay as at Juliers.

50.—As regards the 2 feet thick escarps, if danger be apprehended from the application of powder bags, &c., to blow the wall in, an extra thickness can be given, when necessary, at *Z*, Fig. 4; but the communications, *V V*, throughout, place the defender on all but equal footing with the assailant, in any attempt at systematic "mining" not subterranean. The thin escarp affords greater scope for various devices during the near defence. Now that locomotive steam fire-engines have been invented, some one may again advocate a re-consideration of La Joumarière's hydraulic manœuvres for flooding the nearer saps and lodgments; and thence, the more distant. In 1785 the steam engine was not thought of for such purposes. The thin escarp affords greater facilities for the use of field guns, wall pieces, &c., through small embrazures, loopholes (either ready built or improvised), on the demand of the moment.

51.—In reference to par. 14, Fig. 13 shews how blocks of wrought iron may be formed and laid voussoir-fashion.

52.—In 1854, the Inspector General of Fortifications invited every Commanding Royal Engineer to give opinion as to the best mode of constructing embrazures. It then appeared to me that iron was the only trustworthy material; but we were at that time altogether without available data as to the power of iron in resisting battery. From the slight effect of an 18-pdr. shot that struck a 24-pdr. fully and fairly near the upper end of the first reinforce at 200 yards, I was led to suppose that a cast-iron wall 2 ft. 6 in. thick would be sufficient: the experiment was tried in 1857, and a few rounds from a 68-pdr. at

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* See Corps Papers Vol. VII., Pl. XI., Figs. 11, 10, 9.

400 yards ruined the work. The blocks of iron were in this case laid lengthwise, as if across a casemate front in the usual manner; the courses were connected by a large groove and tongue, also lengthwise.

53.—I then conceived the idea of laying the blocks as voussoirs, to be made of Bessemere's cast-wrought-iron, or of ordinary cast-iron; but no serious effort was made and the matter dropped.

54.—Subsequent improvements in artillery, together with the recent and peremptory demands for *something* that shall be shot proof, have induced me now to reproduce the project, observing that the arched form proposed is well calculated, not only to resist the blow, but to reduce its effects considerably in all cases where it glances off. It can be completed above as the sector of a dome corresponding to the circular arc (in plan) of 140°, now suggested as most advisable.

55.—If Bessemere's cast-wrought-iron should prove, on trial, to be applicable, it would probably be economical as regards weight for weight compared with forged iron; and it would certainly greatly facilitate the construction: the voussoir can then be cast as *a*, *a*, *a*; but if not found advisable, then common wrought iron pieces can be Nasmythed as *b*, *b*, *b*.

56.—The only further detail on which I here touch, is, that these blocks (or iron for any like work) can be laid like masonry in a cement which will rapidly oxidize the interior surfaces of beds and joints, and so convert the whole into one solid mass. (See Appendix B.)

57.—All these points require and invite experiment.

APPENDIX A.

Extract from Bousmard, referred to in par. 42.

" Les parties de maçonnerie de l'orillon que l'ennemi peut voir, sont construites avec un art particulier et fort ingénieux. Derrière un premier revêtement assez mince s'élèvent, dans une direction qui lui est perpendiculaire, de fréquens contre-forts qui s'étendent jusqu'aux pieds-droits des voûtes des souterrains de l'orillon. Ces contre-forts sont eux-mêmes couronnés et réunis par des arceaux, en sorte que toutes les terres des parapets et du terre-plein de l'orillon, sans exception, sont portées par des voûtes qu'il faut enfoncer par des bombes, ou faire écrouler en ruinant leurs pieds-droits à coups de canon, pour détruire ces parapets et former une brèche. Pour rendre difficile la ruine des pieds-droits, et empêcher la descente totale des terres, si les arceaux qui les soutiennent venaient à être crevés, l'auteur réunit ces pieds-droits et les *contrebute* par deux rangs d'arceaux verticaux et concentriques à 6 pieds l'un de l'autre, dont la convexité est tournée vers le dedans, et résiste ainsi facilement à la poussée des terres."

B.

Cement for Iron-work alluded to in par. 56.

Take 3 parts of iron filings.
1 ,, sulphur.
1 ,, sal ammoniac;

work up the whole to the consistence of stiff paste with the least possible quantity of water, and apply it as mortar in the beds and joints of the blocks to be so cemented.

In Liebig's "Handwörterbuch der Chymie," a far larger quantity of iron filings is given: but the above is from one of the leading operative chemists of the day.

Another recipe which I have obtained from one of our largest iron-factories as actually used therein, and which sets almost as hard as the iron itself, is—

50 lbs.	cast-iron borings—larger or finer as for larger or smaller joints.
4 lbs.	sulphur.
¼ lb.	sal ammoniac.

Cold water (to be *well* stirred in) enough to cover the whole mass.

To remain a day or two, with occasional stirring before using.

To be caulked *closely* into the joints.

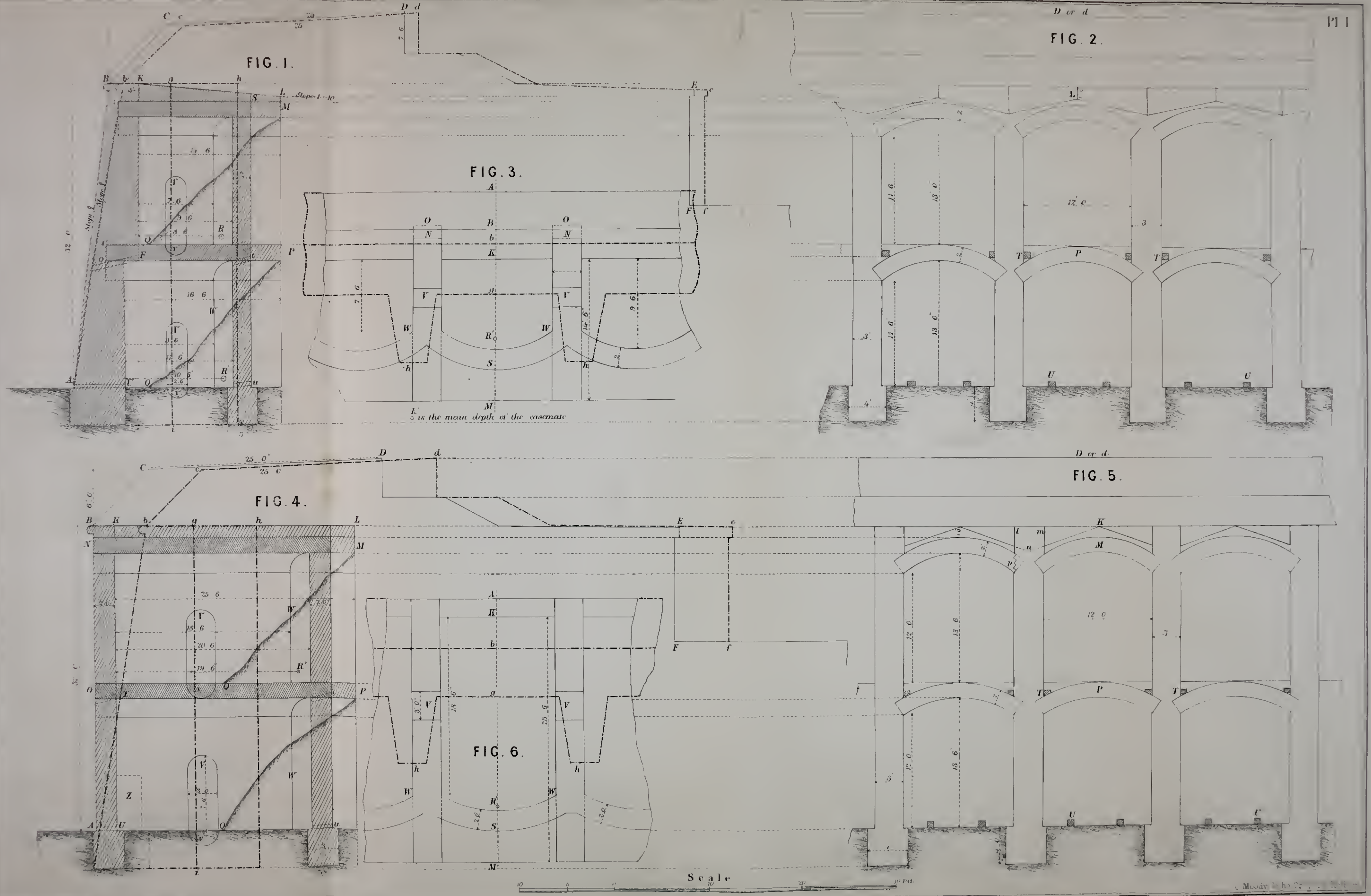
As regards the relative merits of these two recipes, it is conceived that the former, also given on the highest authority, is preferable in laying blocks masonry fashion.—Experiments may however be made on a few blocks to determine this point.

PART II.

VAULTED REVETMENTS.

TRANSLATION.	REMARKS.
These have been carried out in all the escarps at Coblentz as nearly as possible as shewn in Fig. 14; they have been, however, subsequently quite given up; and that, truly, with good reason, since—	
a. Any masonry in 12 feet bays that cannot support itself without Breschebogen, must be very bad.	There is no question about any tolerable masonry being able to support itself in the escarp: the arches in the last are to render breaching more difficult, as each ring must be cut through before the whole can be brought down. When systematically and deliberately breached, one vertical groove will effect this; but this is by no means so often the case as a more or less random or imperfect play of artillery; in which last case it is conceived that it will be indeed difficult to bring down the mere face wall: but this still leaves the vaults and piers with all their merits untouched. Our friends appear to apply the term Breschebogen not only to the vaults and piers, but to the arches turned in the thickness of the escarp.

b. A regular breach will embrace more than one such bay, and then the Breschebogen will be superfluous.	Perfection and infallibility are nowhere claimed for the Vaulted Revetment; but whether one or more bays are embraced, each vault will have to be brought down, and the breach will probably be one that will greatly embarrass the assailants; *no more is to be expected.*
c. The horizontal beds of the masonry in the piers shew many more joints than the vertical beds of the Breschebogen; hence a greater settlement in the former than in the latter. *d.* The arches in the masonry below cannot settle freely upon one another when the centerings are struck.	Here again, the arches in the escarp only can be alluded to; but even then I know not that this unequal settlement occurs in practice. I never saw it happen yet in Von Aster's works. Supposing, however, the objection valid, there can be no difficulty in bonding the rings or arches into each other, so that the whole escarp under the vault becomes one mass, with all the joints radiating from a common centre, as I have seen in a wharf wall at Devonport, built in slate-on-edge between battering-piers.
e. The work is much more expensive.	Bulk for bulk, it may possibly be so; but when the old massive revetment is all but worthless, there is no option but to pay a higher price for efficiency. However, the relative expenses of the two systems can only be determined by comparative estimates varying with localities in every possible way—as intimated in paragraphs 28 and 29.
Hence, we afterwards only let the main arch go through the revetment; and even this is not very expedient; we have therefore recently only let the main arch enter a few inches into the rear. (See Fig. 15).	This is a serious modification of the system, and, in my judgment, a very objectionable one:—the escarp is soon breached, and brings down all that portion of the parapet that rests upon it.
The enemy cannot then at all see where the vaults are; especially when the loopholes are spaced at equal distances.	See paragraphs 24, 25, 26, 27.



K̄ is the mean depth of the casemate

Scale

10 5 0 10 20 30 Feet

Moody [illegible]

FIG. 7.

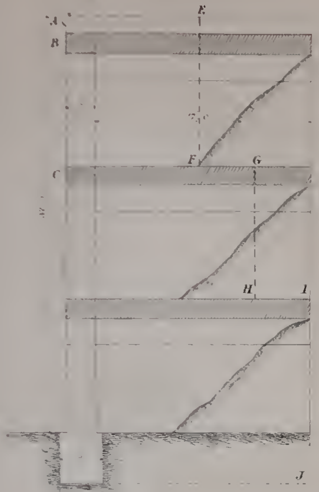


FIG. 8.

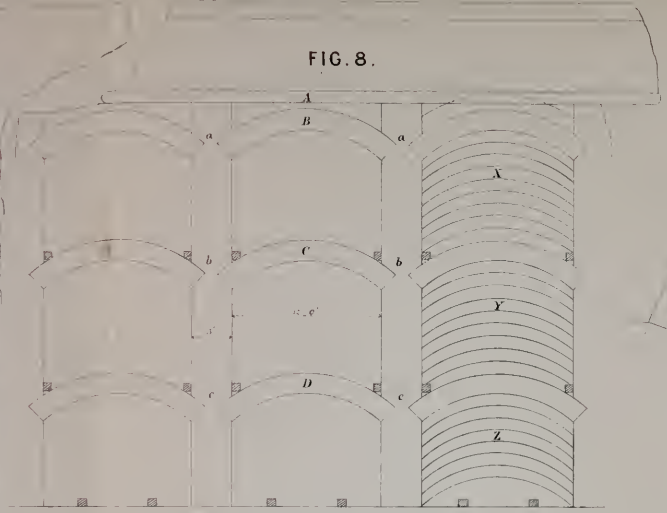
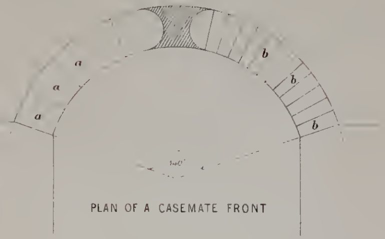


FIG. 13.



PLAN OF A CASEMATE FRONT

FIG. 10.

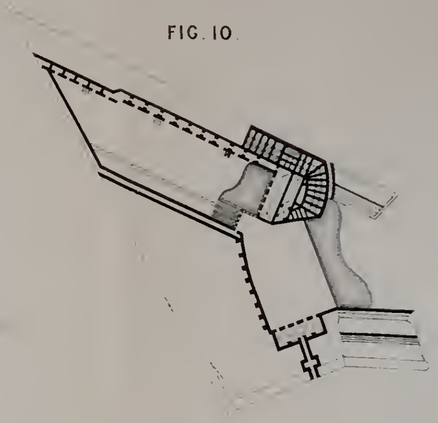


FIG. 14.

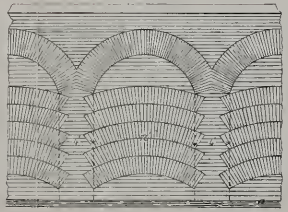


FIG. 11.

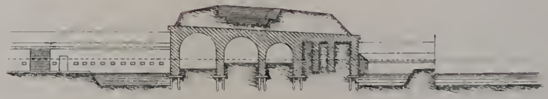
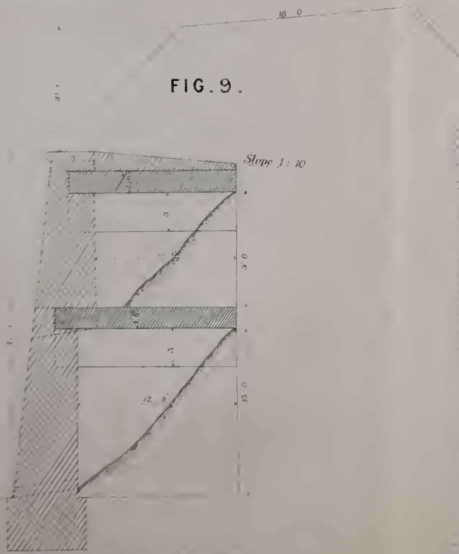


FIG. 9.



Width of Casemates and thickness &c of piers as in Fig 2 5

FIG. 12.

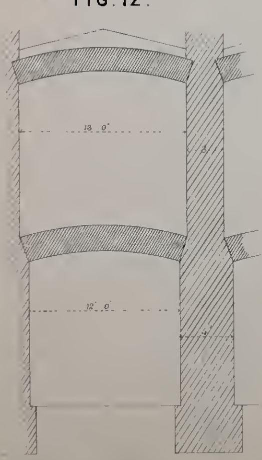
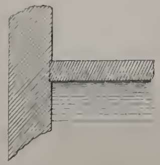


FIG. 15.



Scale

For Figs 7, 8, 9, 12, 13, 14 & 15

J. Moody, Litho 257 High Holborn

The facts that have lately come to our knowledge, respecting the powers of artillery and the strength of iron, must not be allowed to startle us into a panic, and out of the sober proprieties of masonry as, at all events, the *mass* in which certain points may receive help from iron, just, perhaps, as we give a platina or a gold touch-hole to a fowling piece; thus it may, nay, *must*, be introduced at particular points, or for special purposes.

As regards the necessarily low men-of-war fitted for Coles' shields, it would appear, thus far, that they can be easily boarded at all points at the same moment: the musquetry defences as yet proposed are too feeble to stop any considerable body of determined men; and a grenade or two thrown into the shields, or a powder-bag laid on the grating (if so closed), will have much the same effect on the men within, as Sir Richard Grant's dismounted congreve-rocket, which he thrust one night into the embrasure of a Martello Tower, had on its terrified garrison.

Such harbours as Portsmouth admit, it is conceived, not only of the application of the Russian "infernal" principle, but of systematic counter-mines for explosion at different points along the long and narrow channel of approach, especially where the passage can be checked, if only for a few minutes, by booms, there being no other limit to the strength of these last (especially when supported from the shore, as it is presumed they *always* are) than there is to the thickness of plate-iron or to the weight of artillery; there can be no motile agency afloat, that cannot be checked by the unlimited and stationary strength and resources of an intelligent antagonist ashore.

We may also turn our thoughts in other directions, *eg.*,—the timely withdrawal of all guns from the embrasures when their fire is likely to be overborne, without waiting for the (now) almost hopeless application of mantlets; and then, the replacement of the solid shot by shell to be fired over the parapets. This will involve a demand on the further attention of the artillery, to the improvement of howitzer and all other shell-practice to bear upon unseen but well known objects around the work. Well determined charges and elevations —with or without "false marks"—for every significant point, as was done on a small scale in the Baltic some 50 or 60 years ago; some improvement on the common practice of chalking the platforms, &c., &c., &c.

These, however, have neither the interests nor merits of novelty; it will be well to set the mind quite as much on sheer invention as on mere improvement of our existing status, as regards Masonry and Artillery; but in no case to be scared into national bankruptcy by

IRON FOR EVERYTHING!

Let us remember that

NOTHING CAN DO EVERYTHING!

R. J. NELSON,
Colonel, Royal Engineers.

Beaufort Villas, Cheltenham,
17th June, 1862.

PAPER IX.

SUGGESTIONS FOR ADAPTING FORTIFICATION TO THE PRESENT MEANS OF ATTACK.

By LIEUT. COL. GRAHAM, R.E.

It cannot be denied that of late years a grave question has arisen as to the influence which the recent improvements in artillery will have on the relations of attack and defence. It has been doubted, and apparently with justice, if the progress of the art of fortification has been at all in proportion to that of the art of gunnery, the two being so intimately connected that any advance in the one would seem to demand a corresponding modification in the other.

At first sight, it might be imagined that the attack would gain no more by the improvements in artillery than the defence, as the besieger would have to open trenches at a greater distance, and advance more slowly than before at the commencement, being earlier exposed to the accurate fire of small-arms, while the besieged can now increase the length of his lines of defence and develope the extent of his front.

We have however good authority* for believing that on the whole, the power of the attack has been greatly augmented relatively to that of the defence, and, indeed, on a priori reasoning, we should be disposed to conclude from the very theory of the attack, the besieger's superiority of artillery, that any proportionate increase in the power of that arm on both sides, must serve to establish a still greater disparity.

The great advantage to the attack at the commencement of a siege, will, I apprehend, be the great choice of ground afforded for the besieger's batteries by the increased range of artillery, positions from which to breach exposed masonry, take up prolongations of lines for enfilade, &c. The arc of the circle on which the attack is developed is considerably increased, thus affording a superior concentration of fire to the besieger's batteries. The use of lines of detached forts, by giving a great development of front, is a manifest check to this power of concentration on the part of the besieger; but here again the artillery of the defence is massed in different points and would be unable to contend with artillery dispersed along the whole front and concentrating by turns on these different points.

These considerations must lead us to the conclusion that for the future the besieged should not depend on his direct fire for defence, as his guns will never be able to contend with the concentrated fire of the attack.

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* Military opinions of Sir John Burgoyne.

We may indeed consider all systems as fallacious that depend on the principle of direct fire as their basis, and pretend to crush the besieger's batteries before they can open.

If ever a fortress had a powerful fire of artillery combined with great development of front, that fortress was Sebastopol, but I think that those who worked in the trenches during that siege will not be disposed to admit that any artillery fire could absolutely have stopped the progress of our batteries or approaches.

It is true that the besieger will now have to open his trenches at a greater distance (in cases where there is no natural cover near the place) and may perhaps have to commence sapping at 600 or 800 yards instead of at 300. This would certainly retard his advance by day, but by night he will be able to advance as fast and as far by flying sap as in the days of brown bess. Thus the attack may be slightly retarded at the first period, but the artillery of the garrison, once silenced, their musketry fire would soon be overpowered by that of the besieger, aided by a concentrated artillery fire of an accuracy hitherto unknown, under cover of which the assaulting columns might advance, as they did at St. Sebastian. The besieger would probably be able to breach from his distant batteries and descend into the ditch by merely blowing in the counterscarp, trusting to his overpowering fire for cover, and thus dispense with the tedious operations of constructing great galleries of descent, advanced breaching batteries, &c.

Yet it must be admitted that there are some advantages to the defence in the increased power of artillery. Although the actual line of defence is not increased (being limited by the range of grape and canister), yet it is obvious that detached forts may now give an effective collateral fire at great distances, and thus compel the besieger to extend his trenches considerably, and, indeed, render the investment of a large place difficult, if not impossible. A minor advantage to the defence would be the difficulty the besieger must experience in moving about a siege train of the calibre now required.* Yet here modern science meets him with the railway and steam transport. It is possible, however, that the railway might be applied to systems of detached forts, as proposed by Zastrow, for the purpose of rapidly augmenting or diminishing the garrisons at different points, and thus giving to such fortresses a strategic activity, and opening a vast field to military combinations. As yet, however, there is a feeling of insecurity about railway communication, that may prevent this application being made.

In the absence of the definite test of experience there is a great field for speculation and enquiry in all the various branches of defensive strategy; and as discussion cannot do harm, but on the contrary may tend to stimulate enquiry and give confidence, any contribution of thought, however slight, may not be without value, and as such, I would submit this for consideration, that it may be thrown in with other writings as a "pierre perdue," fortunate should it in a small degree assist in raising the future superstructure.

The present may fairly be considered a period of transition in the art of fortification. The bastioned system of Vauban and the early Italian Engineers, is now more or less practically abandoned, and replaced by the polygonal system of Montalembert, as developed by the Engineers of Germany.

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* As the 40-pdr. Armstrong gun, weighing 30¾ cwt., will be most likely employed in future siege equipments, this remark will apply only to the increased weight of the projectile, the gun and charge being lighter than of old.—Ed.

These principles, although they may claim the high merit of having practically converted their adversaries of the French school (as instanced in the fortifications of Lyons and Paris), have not yet been tried by the highest test of all—experience: their application is, therefore, clearly subject to theoretical criticism. With this view, it may (I hope without presumption) be doubted if the German fortifications fulfil all the requirements of modern science.

Without particularising, it is well known that in many German fortresses the *trouées* of the ditches of the ravelin are left open, thereby exposing the enceinte to be breached at long ranges, in others they are merely closed by demi-caponiers which could be easily destroyed from a distance, after which the ditches of the ravelin would be deprived of all flank defence, and the enceinte exposed as before. The long faces of the enceinte and ravelin in the polygonal system, appear as much exposed to ricochet fire as the corresponding parapets of the bastioned system. It is, indeed, pretended that the enceinte is protected from being enfiladed, because by the obtuseness of the angles of the polygon, the prolongations of the faces will generally fall on the ravelins of the adjacent fronts, or at least too near to these fronts for the safety of the besieger's ricochet batteries. It is, however, very doubtful if being masked by an advanced work would do more than somewhat increase the difficulty of obtaining the prolongation of the lines and parapets, which would moreover be facilitated by the superior relief of the enceinte.

It may also be doubted if these ricochet batteries could really be silenced by direct fire; since, as they fire at high angles, they may be as completely hidden as mortar batteries. This would undoubtedly be the case with a ricochet battery of the present long range guns, the position of which might also be sufficiently distant from the fronts adjacent to the one enfiladed to secure it from sorties.

Indeed, it must be remembered that the real power of ricochet fire does not consist in the number of bounds the shot makes; but in the absence of necessity for accuracy of aim and elevation, in proportion to the extent of line enfiladed, so that a few guns enfilading the long line of an enceinte of the polygonal system, would probably do more damage than they would in any position of an attack against a bastioned front. Even supposing such a battery to be at a considerable distance from the parallels of attack, it would yet surely be quite practicable for a besieging army—in possession of the country—to maintain a point of such importance. Sufficient care does not appear to have been taken to protect the concealed masonry from the effect of pitching fire, more especially in cases where the countersloping glacis has been employed to replace the counterscarp. The vital point, the heart of the polygonal system, is the great central caponier; and it cannot, since the experiments at Juliers, be doubted but that this work could be destroyed wherever the prolongation of the main ditch could be taken up. Indeed, as Zastrow, the great advocate of this system, admits, this work is liable to be placed between two fires when each side may be taken in reverse, each ball dismount two guns, &c. There must be also, in the present transition state, a great deal of difficulty in determining the width of the main ditch. The depth of the ditch can only be a question of expense, water-level, and remblai; but in estimating the width, we have to consider how to adapt it so as to obtain sufficient flank defence for the ditch without over exposing the escarp to be breached by distant pitching fire. Indeed, this difficulty seems to constitute a strong objection to this species of flank defence, and has forced Engineers to abandon the great principle of Montalembert of concentrating an overpowering flank fire on vital points, which he effected by making his central caponier of such gigantic dimensions that, as he conceived, no breaching battery could stand before it. This is Zastrow's eloquent introduction of Montalembert:—

"La même tactique qui valut à Napoléon ses victoires, sert évidemment de base aux projets de Montalembert."

"L'Empereur dut en effet le gain de ses batailles à ce qu'il savait concentrer sur des points décisifs d'énormes masses, qui, opprimant promptement l'ennemi, décidaient la victoire—de même, nous voyons dans les projets de Montalembert sur tous les points où il doit avoir une lutte décisive d'artillerie entre l'attaque et la défense, une réunion extraordinairement considérable des bouches-à-feu, souvent dix fois plus fortes que les batteries d'attaque dont elle empêche par conséquent la construction, ou, si cette construction a eu lieu, dont elle réduit promptement le feu au silence."—(Zastrow, Cap. IX, Vol. 2. French Translation.)

How far, we may ask, does our present Fortification respond to this idea?

Looking at the two great schools of fortification, the bastioned and the polygonal, it would appear that while Montalembert may still be styled the prophet of the latter, and has announced ideas that are even now undeveloped, the greatest of recent writers on the bastioned system, one who has combined all that has gone before with much of his own, is Choumara; and it is with his principles that I would propose to reinforce the present German system, and so attempt to realize the theories of Montalembert.

The works of M. Choumara have now been over 30 years before the world, and have excited great and deserved admiration. His luminous principle of the independence of the parapet and escarp has been generally recognized and adopted, though by no means fully. Choumara's idea was that the defence should gain a new field of activity by means of this principle; by giving mobility to the parapets; turning them to reply to the besieger's batteries, or to flank some point menaced by assault. In his own forcible language—"The enceinte is divided into two parts, a permanent part and a variable part, le terrain enveloppé par les escarpes et celui soumis à son influence forment un champ de bataille obligé."—(Mémoires sur la fortification par Choumara).

This principle of the mobility of the parapets, as well as their independence of the escarp, has not (to my knowledge) been adopted, nor has any provision been made for carrying it out in time of siege. Indeed, with the present system of terrepleins with retaining walls for casemates, this idea could not be made available for want of space. Yet, surely this is a most important principle, for it is to the mobility of his batteries and their consequent power of concentration, that the besieger owes his great superiority. At Sebastopol this principle of active defence was applied on a large scale by the garrison, and there they may be said to have had the steep sides of the ravines as their escarps, their "partie permanente, or champ de bataille obligé."

To sum up then, I would suggest considering the following propositions for improving our fortifications, so as to adapt it to resist the present means of attack:—

I. To protect the escarp of the enceinte from being breached by pitching fire, or through the ditches of the outworks.

II. To obtain a flank defence that cannot be destroyed by distant pitching fire, or taken in reverse, and that shall oppose a superior fire to the enemy's counter or breaching batteries on the glacis, without thereby exposing the escarp of the enceinte.

III. To protect open parapets from enfilade.

IV. To afford facility for concentrating or diverging the fire of the enceinte according to circumstances.

For the solution of the first and second of these propositions, I would suggest the use of Choumara's interior glacis. This work (which is simply a glacis in the ditch swept by the artillery of the enceinte) was proposed by Choumara with the object of closing the *trouées* of the ditch of the ravelin without thereby making any "dead ground" unseen from the enceinte. It further shews that this work forces the besieger to make two successive descents, and thus delays him at the most critical period of the siege, when his advance is slowest and loss greatest. Choumara considers that his interior glacis must be crowned before the enceinte can be breached, and that the crowning would be almost impracticable under the heavy fire of artillery and musketry enfilading the besieger's passage up the slope. From the moment of emerging from his great gallery of descent on to the slope of the interior glacis, the besieger is exposed to sorties without having any secure line of defence or any good communication with his supports. He will besides be overwhelmed by fire in front and flank, by hand-grenades rolling down on him, by "bouquets" showering over him, and, not content with all this fire, M. Choumara invokes the opposition element to his aid, by inundating part of the space between the crest of the interior glacis and the counterscarp by means of steam pumps and "batardeaux," thus destroying the enemy's communications, while still preserving his own in the ditch behind the glacis and along its crest.

Experiments are still needed to determine the minimum angle at which masonry can be breached by pitching fire.* So that no certain data can yet be given for determining the height of the crest of this interior glacis, or its distance from the escarp. It is a rule, I believe, that the horizontal angle for breaching should not be less than 50°, † and as this would be firing with full charges, I should suppose that 60° (*i.e.* a terminal angle of 30° with the horizon) would be a safe minimum at which pitching fire with reduced charges would be innocuous.

With regard to proposition II, I would suggest establishing a low caponier with Haxo casemates on this glacis, in the centre of the front, and to conceal it from the country by raising the counterscarp at the salients, so that the besieger's counter-batteries against this caponier may be exposed to an overwhelming fire on the only ground from whence they can see the work.

The method I would suggest to meet propositions III and IV, is simply to indent the parapet, so that each gun is placed in a separate salient, and can traverse through a quarter circle, according to the direction of the embrasure. In many cases, I would recommend the embrasures being ready revetted with gabions or fascines, in three different directions in each indent (keeping of course only one open), by which arrangement the direction of the line of fire could be altered in a very short time, and the parapet would be rather strengthened by the presence of these revetting materials.

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* See Vol. X of Professional Papers, page 168.—Editor's Note.

† It is true (according to Baron Emile Maurice) that by experiments at Metz and Bapaume in 1834, it was shewn that a wall might be breached under an angle of 25° to 30°, with charges $\frac{1}{3}$ weight of shot, at a distance of from 40 to 60 mètres; but these conditions are inapplicable to pitching fire.

By this simple method the guns are not merely secured from enfilade fire, but they can be concentrated on any given point of the ground in front for the purpose of destroying a battery, lodgment, head of a sap, &c.; and it would also afford opportunities for evading the direct fire of the besieger's counter-batteries, without thereby lessening the activity of the defence, by simply changing the direction of the embrasures.

It may be objected that by this arrangement the guns are necessarily placed so far apart, that comparatively few can be placed on the ramparts. This is certainly true, and in the accompanying plan (Pl. I.), the parapet being made 24 feet thick, the guns of the indented portion are placed about 22 yards apart, though this distance might be reduced to 18 yards.

I would, however, submit for consideration, if it is not better to have a few guns, each well protected, and capable of traversing through an angle of nearly 90°, than to have a mass of guns whose number only exposes them to be more easily destroyed. With the proposed arrangement, all available spare guns might be kept under cover in reserve, to supply the place of those rendered unserviceable, instead of being at once placed on the ramparts. Besides, it may be observed that although there are only a small number of guns in each front, the guns of the collateral fronts would come into action, which they would not do in the ordinary trace, and a concentrated fire may thus be obtained in front of each salient. But, indeed, in this project, it is not contemplated to maintain an overpowering direct fire on the besieger's trenches. There, where he can choose his own position, he *must*, in ordinary cases, have the superiority; and we may remember that Ciudad Rodrigo was breached and taken by us with an actual inferiority of direct fire, without rifled artillery. The principle I would seek to adopt is to husband every resource at the commencement of the siege, reserving all the energy of the defence for the critical period of the enemy's arrival on the glacis and counterscarp.

Before proceeding to the description of the accompanying plate, I would observe that I do not pretend to lay down any system, but merely to give some suggestions (necessarily very imperfect) for carrying out the principles I have alluded to. It has been truly said that the time is past for reducing the composition of fronts of fortification to dry and arbitrary combinations of lines and angles, and that, in truth, there is but one system of fortification—that which makes most of the natural advantages and best avoids and foresees the disadvantages.

Description of Plate I.

Taking the exterior side at 600 yards, the escarp is traced by drawing lines from its extremities to the end of a perpendicular which has been set off about 8 yards inwards. A slightly tenailled form is thus given to the enceinte, for the purpose of placing the caponiers of the main ditch at the salients instead of in the centre of the front, by which arrangement it is rendered difficult, if not impossible, to destroy them by firing along the prolongation of the ditch. The ditch is 42 feet wide at bottom, and is flanked by the two caponiers at the salients *c c* ; on the top of these caponiers two demi-caponiers, *d*, *d*, have been placed so as to increase the flank fire of the ditch, and to flank the exterior slope of the parapet of the chemin-des-rondes. The demolition of these small caponiers (which are however well covered) would not affect the work below, and a total flank fire is thus obtained of 4 guns and 32 muskets per front, the fire of which crosses in the centre.

The escarp is 25 feet high (its top being 5 feet below the level of the ground), and the revetment of the interior glacis is 15 feet high, leaving 15 feet unrevetted for the sake of economy.*

Chemin-des-rondes.—The earthen chemin-des-rondes of Choumara has been adopted in place of the ordinary masonry wall. The parapet of this work has a command over the country of 12 feet 6 inches, except at the salients, where it has a command of 18 feet 6 inches. From this work, the slope of the interior glacis and the greater part of the ground in front may be swept by musketry fire. To protect the riflemen on the banquette from enfilade, the interior crest of the parapet, above the banquette, is indented, as shewn (Pl. I, Fig. 1). The chemin-des-rondes is from 6 to 12 feet wide, and is flanked by casemated traverses (*t*, *t*, *t*, Pl. I, Fig. 1,) at intervals of 75 yards. Each traverse has a cross fire on its salient from the two adjacent traverses, and the loopholes may easily be laid out, so as not to permit of their firing into one another.

This form of chemin-des-rondes may be objected to, as Choumara applied it to the bastioned system ; but in the polygonal system (which affords so much interior space) I cannot but think it far preferable to the masonry chemin-des-rondes. By its indestructibility and retired position, it would enable the garrison to maintain a powerful musketry fire to the last, and it also affords a secure line of communication ; neither of which advantages are shared in an equal extent by the masonry chemin-des-rondes. With this secure earthen parapet, the chemin-des-rondes may be used as an emplacement for mortars, or for posting troops to resist the final assault. By the proposed arrangement it also acts as a "couvre-face" to protect a retaining wall of 10 feet height in front of the parapet of the enceinte (Pl. I, Figs. 2, 3). I would propose loopholing this wall, and connecting it with the barracks and magazines underneath the terreplein of the enceinte. By this means great facility would be afforded for draining and ventilating these bomb-proofs, besides obtaining a strong line of retrenchment and economising the space, otherwise taken up by the exterior slope of the parapet. Like all revetments "en décharge," the piers of the arches supporting the earth above are built perpendicular to this retaining wall forming a series of vaulted chambers, any of which might in a very short time be built up solid with sandbags on the besiegers commencing a breach. This suggestion will, I conceive, meet the objection that, by piercing this retaining wall, a breach may be made through the body of the enceinte. It may, however, be said that this is merely a modification of the ancient, now disused, "fausse-braie." According to Zastrow, the objections to the "fausse-braie" are—1st, it divides the body of the place into two stages, thereby facilitating escalade; 2nd, the lower level is untenable when the vertical fire of the besieger commences, affording no command over the glacis.

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* Except at the salients opposite to the caponiers where the slope of the interior glacis is revetted to the top, both to save space and to increase the difficulty of a descent at these points.

The first objection cannot, I think, be applied to the arrangement here proposed, which appears to render escalade simply impossible. Here, the escalading party would only emerge from the flank fire of the caponier at the salient, and gain the superior slope of the lower parapet, to be exposed to the artillery fire of the enceinte; then, entering the chemin-des-rondes, they would be met by a cross fire from the traverses *t*, *t*, *t*, and direct fire from the casemates, under which they would have to bring on their ladders to scale the retaining wall. That the second objection does not apply may be seen by referring to section Pl. I, Fig. 1, where the fire from the lower parapet is seen to sweep the glacis.

Parapet of Enceinte.—The parapet of the enceinte is indented, as has been already stated, for about 170 yards on each side of the salients; a sort of curtain is thus left for direct fire in the centre of the front, which, it is supposed, could not be easily enfiladed over the indented portions. The parapet is throughout 24 feet thick, and, to economise interior space, only the merlons are indented; the part of the exterior slope, below the sill of the embrasure, being in line with the unindented portion. By squaring off the re-entering angles of the interior crest, and giving at these points a clear width of 12 feet to the terreplein for a roadway, the inner line of the retaining wall of the terreplein is drawn two yards further in, than would have been necessary, had the parapet not been indented. Thus, in the plan, Pl. I, Fig. 1, the retaining wall of the terreplein of each half-front is in the same line, and at a distance of 13 yards from the original interior crest line, instead of being 11 yards as usual. Thus, two yards multiplied by the length of the front represents the loss of interior space due to the proposed indentation of the parapet; and, indeed, this can scarcely be called loss since all the space beneath the terreplein may be casemated and available as bomb-proof barracks, stores, &c.

Interior Glacis.—As before stated, the upper half of the interior slope of the interior glacis (corresponding to the counterscarp of the main ditch) is left unrevetted. Its crest is (± 0) 5 feet above the cordon of the escarp, and a shot passing over it so as to strike the latter near its foot would have a terminal angle of about 30°. The slope of this glacis is about $\frac{1}{8}$, and is swept by the artillery fire of the enceinte, and by the musketry of the parapet of the chemin-des-rondes.

Central Caponier.—The great central caponier (C) lies on this slope, and consists of ten ordinary Haxo casemates on each side of an earthen traverse, as shewn in plan and sections of Plate I.

The difference of level of any two adjacent casemates is 2 feet 6 inches, and the arch of the casemate covers the crest of the traverse, so as to give protection from vertical fire.

Besides reserving a concentrated fire for the arrival of the besieger at the salients, some of the guns of these central caponiers might be employed in enfilading or shelling the besieger's works and batteries at an early period of the siege.

Counterscarp.—The counterscarp is traced so as to converge towards the salients of the polygon rising gradually as it approaches these points, so as to maintain the necessary height of 15 feet (the slope of the interior glacis being everywhere nearly equal). At the salient it is raised to about 18 feet above the level of the ground, and the ground then falls with a gentle glacis slope towards the country. By this arrangement, the central caponier is entirely concealed from the country.

The front of the central caponier is defended by a loopholed wall flanked by a small caponier, and before this there is a sort of triangular traverse, the top of which falls with a glacis slope (swept by the fire of the enceinte) until it meets the foot of the salient of the counterscarp at 18½ feet below the level of the ground (see Pl. I, Fig. 2).

Covered-way.—Considering the object of a covered-way to be to give an emplacement for riflemen and to facilitate sorties, I have supposed the parapet of the chemin-des-rondes to fulfil the former condition, and have traced a covered-way only at the salient of the counterscarp in the centre of the front. This point being nearest to the enemy's trenches must be most convenient for making sorties, and at the same time it is best supported by the fire of the enceinte and by the communication through the central caponier.

So long ago as 1589, covered-ways "en cremaillère," without traverses, were recommended by Speckle, and the latest opinion seems to confirm his judgment. The ordinary method of indenting the parapet of the covered-way does not, however, provide for a fire in a direction parallel to the capital, and from the minuteness of the brisure, it can scarcely be said to give protection from enfilade. By simply indenting the interior crest in the way already proposed for the enceinte and chemin-des-rondes, it is conceived that a better cover would be obtained against ricochet fire, and, in a salient work, a line of fire more or less parallel with the capital, as the salient angle varies from 90°. In fact a covered-way so traced would consist of a series of rifle pits placed "en échellon," well connected and yet affording no cover to the enemy when taken.

Attack.—The only point necessary, for the sake of comparison, to consider, is how to silence the central caponier. There is certainly a want of precise knowledge as to the power of distant pitching fire, but I cannot conceive it possible to silence batteries with Haxo casemates, from a distance, without seeing them; for the vulnerable points are so small compared with the mass of earth in which the shot and shell would bury themselves almost harmlessly, or at most doing damage that could generally be repaired. In this case too, the variable level of the work would, I conceive, considerably increase the difficulty of obtaining accuracy of practice. To attempt to silence the caponier by direct fire from the crowning of the glacis at the salients of the polygon would appear quite hopeless. Here there is room for only four guns (*g*, *g*, *g*, *g*, Plate I, Fig. 1,) which would be opposed by 10 guns of the caponier attacked, 10 guns of the caponier of the collateral front, and 10 guns from the parapet of the enceinte, in all 30 guns, of which 20 have not been seen before. The besieger might also attack the central caponier in flank by advancing on the centre of the front and descending the counterscarp at the salient of the covered-way on to the triangular glacis traverse. To do this, however, he would have to brave the concentrated fire of the whole line, as every gun and rifle of the front can be brought to bear on the centre, and it is difficult to see how he could ever emerge from his great gallery of descent. Even when he has crowned the crest of the glacis traverse, he has no means of breaching the loopholed wall at the flank of the great caponier, and he would scarcely attempt to carry the whole work by assault, protected as it is by a ditch (see Pl. I, Fig. 3) flanked by the fire of the enceinte.

Should he have recourse to mining, it is supposed that he would even find this tedious operation, much more tedious than usual, for owing to the distance of the counterscarp from the works attacked, he would have a greater distance to drive his mines.

Supposing, however, the great central caponier taken, the besieger would still have to dispose of the caponiers at the salients of the enceinte flanking the main ditch. It might be objected to the arrangement of placing the caponiers at the salients, that the besieger's efforts may all be concentrated on one point, and that point the weakest and most defenceless against his advance, the erection of his breaching batteries or assault. By the arrangement here proposed, his efforts will have been hitherto directed against the centre, but now he has to diverge again to the salients, to establish another communication through the counterscarp at that point, and then connect his attack by crowning the crest of the interior glacis.

As before stated, this trace (Pl. I, Fig. 1) does not pretend to do more than attempt to illustrate the principles that I conceive should guide us in designing fortifications. It might in practice be desirable to slightly increase the tenailled form for the purpose of guarding against the possibility of shot or canister glancing off the escarp from the opposite caponier or enemy's counter-battery, or, indeed, to abolish the tenailled form altogether and to place the caponiers at the alternate salients. Among the many other imperfections of this trace it may be noticed that the remblai considerably exceeds the deblai. Not that I suppose their exact balance should be admitted as an essential for any other than field fortification, as I think this must give way to more important principles. "If there is a superabundance of earth from the ditch," says Choumara, "it must be used to strengthen and raise the parapets and traverses—if not enough earth it must be got elsewhere." In most cases earth might be obtained by excavating broad and deep cunettes in the ditches, or by prolonging the slope of the glacis after its intersection with the plan of site.

Expense.—"Those who oppose any new ideas on Fortification, on the ground of the increased expense comparatively with that of the old methods, should, to be just, be able to bring back the Attack to what it was in former times," says Merkes. The expense of the attack will be now vastly increased by the transport and maintenance of a siege equipment of rifled cannon of large calibre, &c.; and the expense of the defence must necessarily increase in proportion. There is no economy in inefficiency. Quoting again from Merkes (Examen Raisonné de la Fortification). "Dufour and Mandar say :—'Ce n'est rien faire en fortification que de ne faire qu'à demi.'"

In order, however, to obtain some comparative view of the expense of a front, such as the one here proposed, relatively to others, I have taken the data from Merkes (Examen raisonné, &c.), and calculated the expense according to what I believe to be reasonable English prices. According to this I cannot estimate the earth-work—considering the height to which it has to be raised—at less than 1s. per yard cube.* The masonry I have estimated at £1 per yard cube. At these rates the following table shews the comparative expense of the front, as in Plate I, relatively to other fronts :—

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* Mr. Fergusson takes 3d. as his price; Colonel Merkes about 3¾d.

TABLE OF COMPARISON.

Description of Front.	No. of yards cub.		Length of front in yards.	Expense per front.	Expense of enclosing a space equal to a Hexagon of 600 yards side	REMARKS.
	Masonry.	Earth.				
				£	£	
Vauban's 1st system	Not stated.		360	69,875	698,750	
Vauban's 3rd system, New Brisach	75,414	355,049	384	93,166	903,710	
Cormontaingne	85,017	313,908	360	100,712	1007,120	
Bousmard	86,324	326,988	360	102,674	1026,740	
Choumara	88,350	340,067	481·19	105,353	790,147	
Present Project	100,226	293,740	600	110,413*	662,478	£57,184 for bomb proof casemates under parapets and revetments en décharge.

By this table the proposed Front would appear to bear comparison, in point of expense, even with Vauban's 1st system, and that, to enclose equal areas, the cost is only ⅔ of Cormontaingne's system.

It is true that this expenditure provides for no raveiins or other outworks; but it does not appear in accordance with the spirit of the polygonal system, to have such outworks around the enceinte.

Montalembert, in his early criticisms on the bastioned system, states that the outworks should be confined within the main ditch, and modern practice accepts this principle generally in the case of enceintes in connection with detached forts, witness—Paris, Rastadt, &c.

Yet the strength of the enceinte should not on that account be neglected. The Prussian Engineer General Brèze, says:—"The main position then should always be strong enough to maintain a siege with effect, even after the advanced outworks have been destroyed; *and the defence should gain in energy in proportion as that of the besiegers begins to slacken.* The principal enceinte should therefore be the strongest part of the position, unless particular circumstances in the formation of the ground render a deviation necessary." †

The front here proposed may be assumed as part of an enceinte supporting a line of detached forts, and it attempts to respond to the conditions required by General Brèze, especially those put in italics. (*sic* in original.)

There is yet another point that claims the consideration of all who have made fortification a subject of thought.

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* This estimate is necessarily a rough one; but I believe that due allowance has been made for all the masonry, as shewn in Pl. I. The great central caponier is estimated at £237 per gun, or £4,740.

† Aide-Mémoire to the Military Sciences, Vol. II, page 53.

The reproach, made by the Engineers of the school of Noizet to those who adopt the polygonal system, is, that they have abandoned the great principle of making the enceinte flank itself; that they have entrusted the entire flank defence of a front to a separate work, which, once destroyed or taken, leaves the enceinte almost defenceless. It should be considered if this must be accepted as an essential defect attendant on the caponier form of flank defence.

It is well known that Montalembert preferred his tenailled to his polygonal system, and proposed applying it to fortifying Cherbourg. In this tenailled system (where, as every re-entering angle is a right angle, there must be a perfect flank defence of the enceinte) Montalembert keeps his masonry low, relying on his overpowering flank fire to crush his enemy at close quarters; but in his polygonal system—the prototype of the modern German fortification—he apparently felt the weakness of his flank defence, and endeavoured to obtain a superiority of direct fire, and, with that object, did not hesitate to expose his masonry.

This method is however clearly impracticable against modern artillery, and it may be said that Montalembert's tenailled system, involving the extensive use of casemates exposed to direct fire, is also impracticable. I would, however, propose applying the tenailled trace without using casemates, but simply indenting the parapet on the principle already described and shewn in Pl. I.

Description of Plate II.—Plate II shews a small fort constructed on this principle. The magistral lines of each half of the front form an angle of 135° in the centre, so that the two halves can give reciprocal flank defence when required. The caponiers of the main ditch are placed at the salients, as in Pl. I, the great caponier *(H)* flanking the interior glacis of the front with 16 guns, and the interior glacis of the side faces are flanked by *(hh)* demi-caponiers of similar construction having 6 guns each. To prevent any possibility of breaching the escarp at the re-entering angle, it has at this point been traced parallel to the exterior side of the front. By this arrangement also, interior space is gained for the construction of a casemated mortar battery *(M)* for 9 mortars.

This may be thought to look very like a bastioned front, and indeed it is, with the important exception that the line of the escarp does not follow the parapets of the flanks, and therefore admits of being flanked by caponiers. The flanking guns here are also well protected from enfilade, and capable of being traversed in an angle of 90°, by altering the direction of the embrasures as before stated. The interior space is evidently greater than it would be in a bastioned fort of the same extent. The caponier on the interior glacis, and indeed the interior glacis itself, are not essential to this trace, but must be admitted to give great increase of strength.*

It may be said that this principle of the enceinte flanking itself, is not neglected in our system of detached forts, since each fort may be considered as a bastion flanking the adjacent one. Still, the ditches are not thus flanked, and, indeed, there must occur many positions where this collateral defence cannot be applied, owing to want of space or other circumstances; and in such cases a fort should be capable of supplying its own flank defence and cross fire on the enemy's approaches.

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* In the case of a fort on the brow of a hill where there would not be space enough to give the saliency here shewn, the line of counterscarp may be taken inside the triangular traverse (*a*, *a*, *a*, on Plan).

In his severe but powerful criticism on the French forts of Lyons, Zastrow says :—" For what purpose are caponiers now constructed ? Evidently to procure up to the last instant of defence an effective flank fire to the ditches and faces of the fortification. What should be the conditions of the caponiers to attain this object ? They should contain enough pieces to be well able to sustain a conflict with the counter-batteries that the enemy raises against them on the crowning of the glacis. This is why Montalembert always opposes to the adversary a four-fold, five-fold, sometimes ten-fold number of pieces, which prevents the enemy's completion of the counter-batteries, or instantly destroys them if they are completed. But the French caponiers of the forts of Lyons do not contain more than half the number of pieces that could be placed in the enemy's counter-batteries, &c."—(Zastrow's History of Permanent Fortification.) It is for us to consider how far these remarks are just and applicable to our own detached forts.

As stated in the commencement of this essay, I believe this to be a period of transition in the art of fortification, when various opinions may be hazarded ; but whatever may be the system we shall ultimately adopt, I believe we should, in the meantime, beware of sacrificing flank defence for direct defence. The Swedish Engineer, Virgin, the inventor of the mortar casemates, and author of, perhaps, the most ingenious system of fortification that has ever been proposed, says—" Every system of fortification may above all be appreciated by the size and excellence of its flanks, supposing these advantages not to be obtained at the expense of the other parts of the fortification."

G. GRAHAM,
Captain, Royal Engineers, and
Brevet Lieutenant-Colonel.

Pl. 1

PROPOSED MODIFICATION OF A FRONT.

REFERENCES.

C	Central Caponier for 20 Guns & 4 Howr
c c d d	Caponiers of Main Ditch
t t t	Flanking Traverses of Chemin des Rondes
s s s	Steps to Parapet of do

Note. The Figures shew the Heights with reference to the Plane of Site

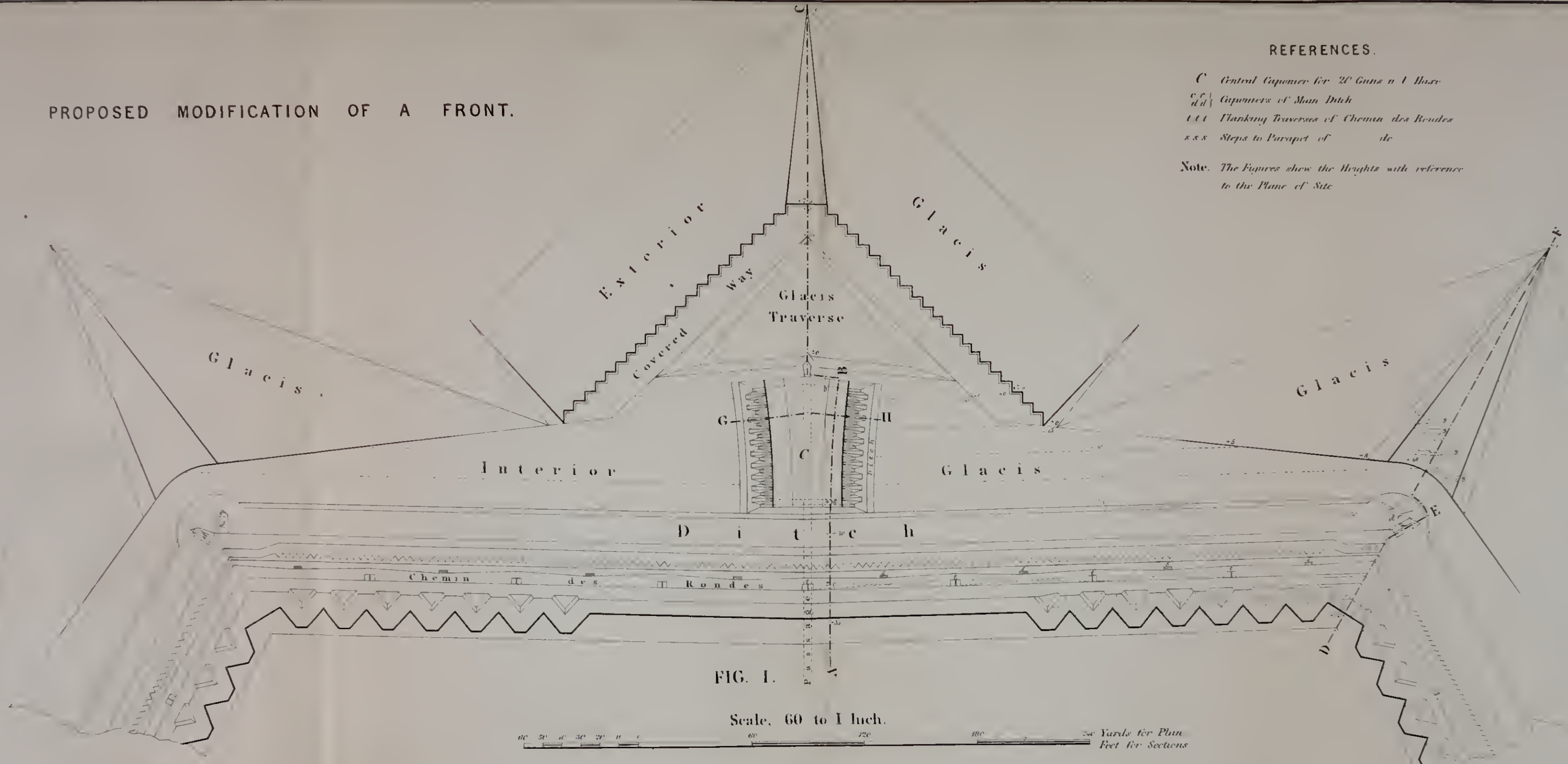


FIG. I.

Scale, 60 to 1 Inch.

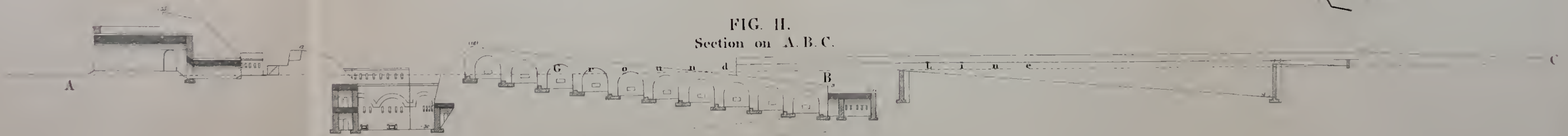


FIG. II.
Section on A.B.C.

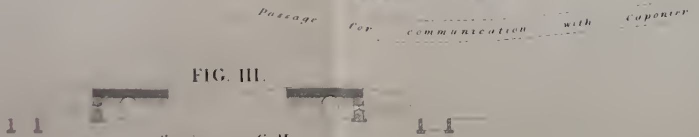


FIG. III.
Section on G.H.

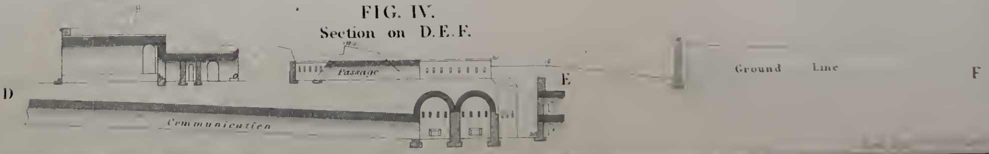
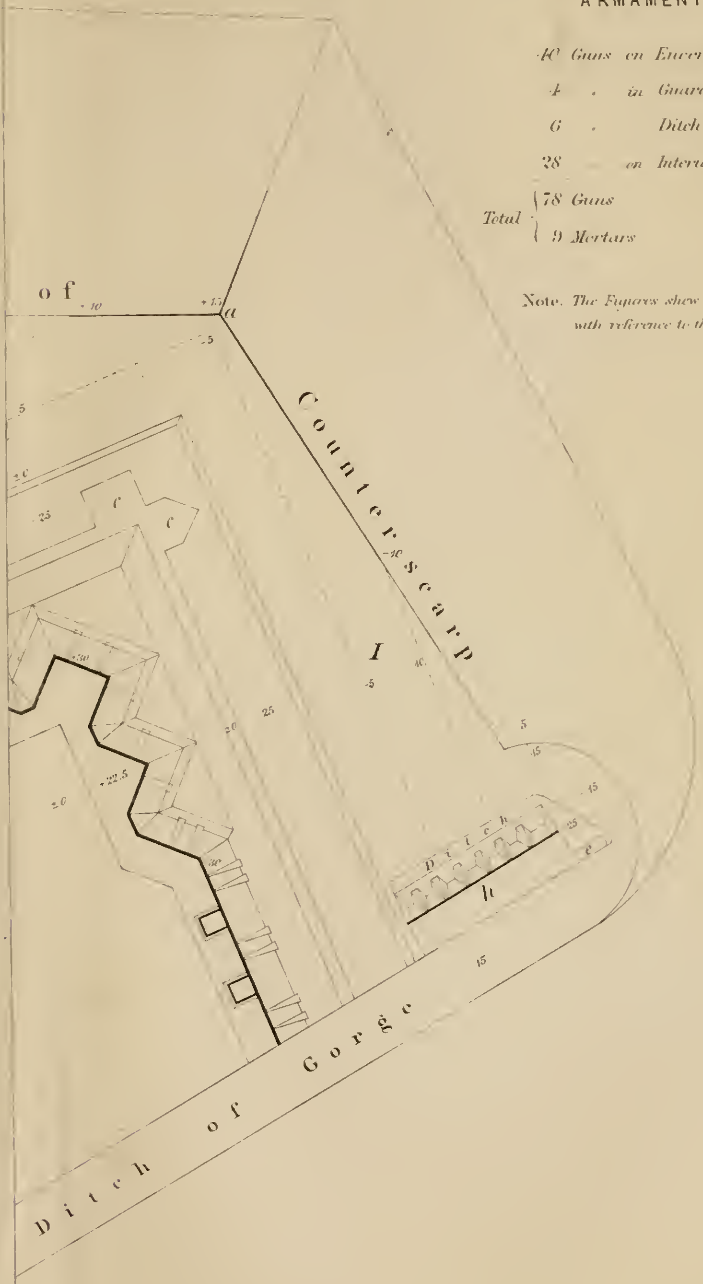


FIG. IV.
Section on D.E.F.

Pl. II

OF FLANK DEFENCE.



ARMAMENT.

40 Guns on Enceinte
4 " in Guard House
6 " Ditch.
28 on Interior Glacis.
Total { *78 Guns*
{ *9 Mortars*

Note. *The Figures shew the heights with reference to the Plane of Site*

[illegible]

PLAN OF A DETACHED FORT ILLUSTRATING PROPOSED PRINCIPLES OF FLANK DEFENCE.

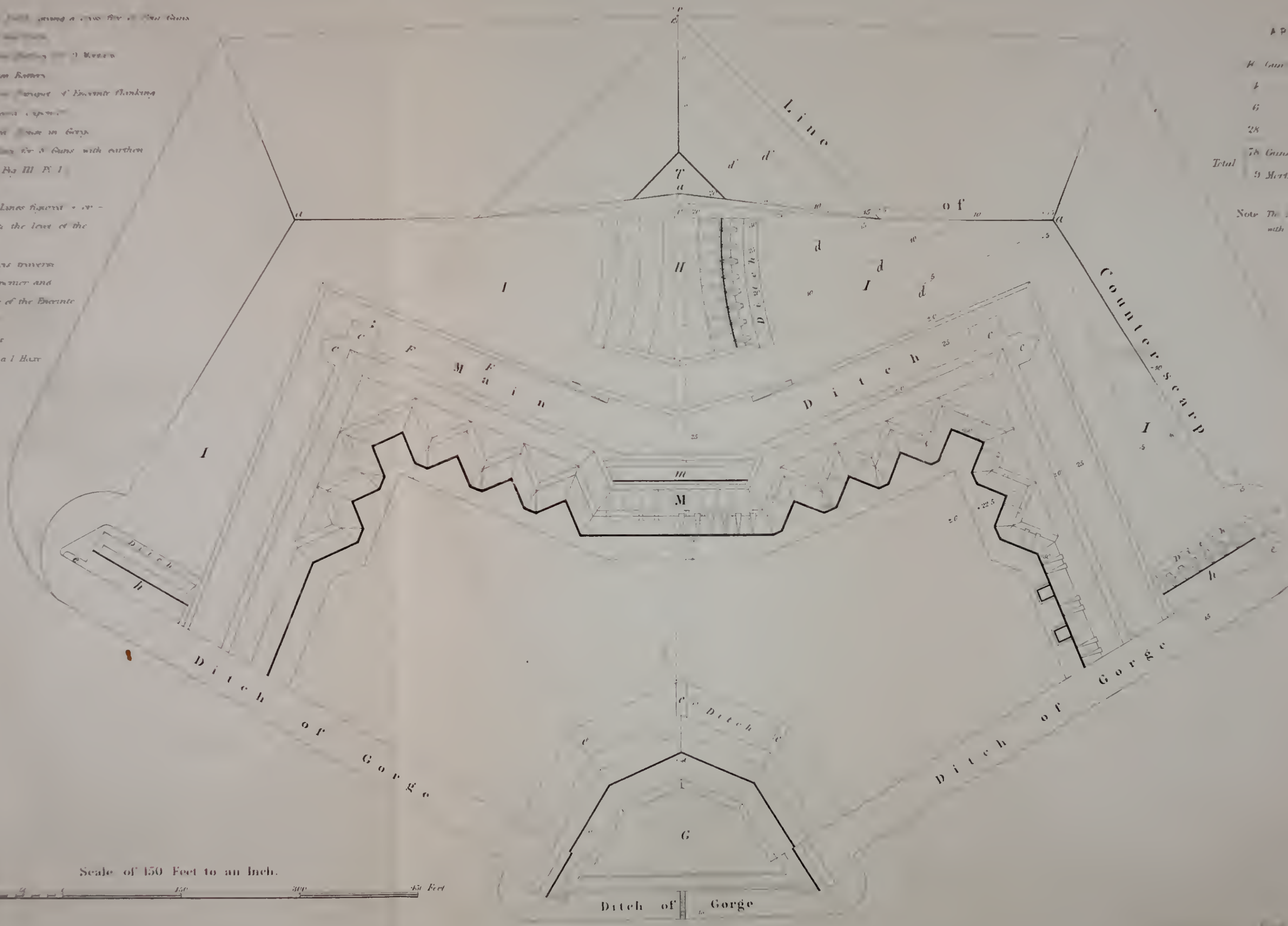
REFERENCES

[illegible] [illegible] of [illegible] [illegible] giving a cross fire of [illegible] Guns
on the [illegible] of the [illegible]
M Casemated Mortar Battery for 9 Mortars
m Magazine for Mortar Battery
F F Guns of the [illegible] Parapet of Enceinte flanking
the [illegible] and Caponier
G Defensible Guard House in Gorge
H Caponier 2d Class for 8 Guns with earthen
[illegible] (See Fig III Pl I)
I I I Interior Glacis
[illegible] Dotted contour Lines figured [illegible]
with reference to the level of the
Country
T Triangular Glacis traverse
covering the Caponier and
swept by the fire of the Enceinte
d d' Openings to D
c c c Small Caponiers
h h Demi Caponier a 1 Haut

ARMAMENT

40 Guns on Enceinte
4 " on Guard House
6 " Ditch
28 " on Interior Glacis
Total 78 Guns
9 Mortars

Note The figures show the [illegible]
with reference to the [illegible]



Scale of 150 Feet to an Inch.

0 150 300 450 Feet

PAPER X.

ON THE PRESENT STATE OF OUR KNOWLEDGE OF THE PHOTOGRAPHIC IMAGE.

BY LIEUT. A. CUNNINGHAM, R.E.

In this paper it is not my design to enter into a discussion of the numerous processes, more or less beautiful, met with in photography in its widest sense. For interesting as such researches would be, it would not be possible to condense such a mass of matter into the requisite limits; still less would I put forward any opinions of my own; indeed, it cannot be supposed that any of the matter of this paper is original; nevertheless, I think it will be interesting to examine in detail, what is known of the chemical nature of the reactions of one of our common processes. For this purpose I have chosen the printing process as one that has been the most examined, and as one of the best known to all of us; of course I speak of the common *chloride of silver* process. I am aware that there are an immense variety of others; indeed, I believe that there is no substance known, which, if it gives a coloured precipitate with a re-agent, will not produce what is termed a proof or print; still, from the extremely intricate nature of the chemical and molecular actions that go on in each one of them, it would be impossible to follow out more than *one* in detail, as I propose doing with the common *chloride of silver* process.

These reactions are so intricate, when all viewed at once, and the quantities operated on so minute, that it is next to impossible to obtain a trustworthy result from a general analysis of the whole number of materials, acting on each other at once, as is the case in practice.

It will be necessary then to examine each successive stage of the decompositions, step by step, as it were, beginning with the more simple case, and proceeding to the more complex, until we attain the form used in practice.

Let us then consider first the method of sensitizing a print.

First, we have the paper, which may be regarded as pure cellulose ($C_{24} H_{20} O_{20}$), a sort of neutral substratum; I call it neutral, because, as far as we know, it takes no part in the reactions which follow, but may be compared to the glass in the collodion process; but, inasmuch as paper is generally bibulous or absorbent, it becomes necessary to cover the paper with a sort of size, generally consisting of starch or gelatine. Amongst these also must be reckoned albumen, which is now so generally used as an extra glazing—(these are represented in the glass processes by plain, that is uniodized, collodion). These now are all organic compounds, and each one induces a peculiar complication in the more simple reactions of the inorganic salts which follow. It is now usual to float the paper on a solution of an alkaline chloride, chloride of sodium ($Na\ Cl$) (common salt) for example, of which the paper imbibes a certain amount. The albumenizing (when albumen is used) is generally performed at the same time. The paper is now floated on a solution of a soluble salt of silver, for which purpose the nitrate, as being easiest prepared, and as yielding nothing but soluble salts in subsequent operations, a very important point, is preferred. Everybody is acquainted with the reaction between the chloride of sodium and nitrate of silver which follows. An insoluble chloride of silver ($Ag\ Cl$) is precipitated in the pores of the paper, and nitrate of soda ($NaO.\ NO_5$) which is soluble, as I just said, forms partly in the bath and partly in the paper as is evident from the equation—

$$\underbrace{AgO.\ NO_5}_{\text{nitrate of silver,}} + \underbrace{Na\ Cl}_{\text{chloride of silver,}} = \underbrace{Ag\ Cl}_{\text{chloride of sodium,}} + \underbrace{NaO.\ NO_5}_{\text{nitrate of soda.}}$$

As to the organic compounds or sizes, starch and gelatine appear to be without action either on chloride or nitrate of silver; but albumen combines with nitrate of silver, forming a white sensitive precipitate termed albuminate of silver, which is represented by the very complicated formula $AgO.\ HO.\ C_{144}\ H_{100}\ N_{18}\ S_2\ O_{42},\ 2\ HO$ which is sensitive to light.

This is an important property of albumen, as it causes the print to be richer in silver, and therefore more sensitive.

Any albumen which has not thus combined with silver is immediately rendered insoluble by the free nitric acid. This shews that albumenized prints will safely stand washing without much fear of the glaze coming off, which cannot be said of gelatine.

Further, from the manner in which the paper is floated, a considerable excess of nitrate of silver is absorbed by the paper. It will be shewn presently that this is a very important point.

The paper is now dried, and is fit for the printing frame.

To sum up then, a print before exposure consists of a neutral stratum of cellulose, supporting a size of either starch or gelatine, with which may be coagulated albumen. Intimately dispersed throughout the size is chloride of silver ($Ag\ Cl$), with albuminate of silver, in contact with which is chloride of silver ($AgO.NO_5$) in excess, and also some nitrate of soda ($NaO.\ NO_5$). The print is now exposed to the action of light. I spoke before of the extreme difficulty of investigating the action of light on all these substances at once. Let us then endeavour to eliminate some of these as either unnecessary, or at any rate secondary, in the reactions; and by a judicious mixture of synthesis and analysis proceed from the simplest case presented to us, to the complicated one I have just mentioned. Of all the substances sensitive to light which I have just mentioned as existing on the proof, the staple, if I may so say, is chloride of silver ($Ag\ Cl$). The simplest case then presented to us is a plain (that is unsized) sheet of paper, sensitized with chloride of silver alone. This may be managed by floating, as usual, on baths of chloride of sodium ($Na\ Cl$) and nitrate of silver ($AgO.\ NO_5$), and then well washing the print, which will remove excess of nitrates of silver ($AgO. NO_5$) and soda ($NaO. NO_5$). It remains, then, to enquire what is the action of light on this chloride of silver ($Ag\,Cl$). And here I must premise that, in speaking of the action of light, I mean that portion of the rays from the sun known as the actinic rays, which I suppose, every one is willing to grant are independent, to a great extent, of many at least of the luminous rays.

All then are agreed that the action of light (*i.e.* of the actinic rays) on a substance is similar to the action of the inner blow-pipe flame, *i.e.* that it is a reducing agent; that it loosens the affinities of the combined elements for each other, and tends to isolate them, or to make them take up more stable combinations.

But as to the extent of the reduction that takes place there is some variance; two views have been especially advanced.

(a) Some consider the reduction to be entire—that a complete isolation of the elements takes place according to the equation $Ag\,Cl = Ag + Cl$.

(b) Others consider that there is an intermediate and less complete reduction, thus :—

$$\underbrace{2\,Ag\,Cl}_{\text{chloride of silver,}} = \underbrace{Ag_2\,Cl}_{\text{subchloride of silver,}} + \underbrace{Cl}_{\text{free chlorine.}}$$

The former view is, I think, the most received, being that of the French chemists, and many English and American ones; the latter that of a small section of English ones.

It is to the former I wish specially to call attention, because the experiments which I have been able to collect on it appear to be so systematic and conclusive as to leave little doubt of its truth. There is no detailed and systematic view of the other theory published, that I am aware of.

To reason, then, on this, I must premise that metallic silver is soluble in nitric acid ($HO. NO_5$); that neither chloride ($Ag\,Cl$) nor subchloride of silver ($Ag_2\,Cl$) are; that chloride of silver ($Ag\,Cl$) is soluble in ammonia ($NH_4\,O$); but that ammonia ($NH_4\,O$) decomposes the subchloride ($Ag_2\,Cl$) into metallic silver and its chloride ($Ag + Ag\,Cl$), which latter dissolves in the ammonia.

(1) There is then no doubt that chloride of silver ($Ag\,Cl$) is reduced on exposure to light, chlorine being set free ; but to prove this, it is only necessary to expose to the sun distilled water with chloride of silver ($Ag\,Cl$) in suspension, and, in the course of a short time, free chlorine is detected in the liquid by its bleaching vegetable colours, and by the curdy white precipitate with a drop of nitrate of silver ($AgO. NO_5$)

(2.) A precipitate will be noticed in the last experiment. To see whether this is metallic silver (Ag) or subchloride of silver ($Ag_2\,Cl$), let equivalent quantities of nitrate of silver ($AgO. NO_5$) and chloride of sodium ($Na\,Cl$) in solution, be mixed in a flat dish, and the precipitate, which everyone knows is chloride of silver ($Ag\,Cl$) be washed, dried, and exposed to the sun. The violet or brown precipitate thus obtained will consist of either silver (Ag) or subchloride of silver ($Ag_2\,Cl$) with nascent chlorine mixed with undecomposed chloride of silver. It is first washed to remove the free chlorine, and it is found that nitric acid ($HO. NO_5$) dissolves a considerable quantity of the precipitate with evolution of red fumes of nitrous acid (NO_4). This proves the presence of metallic silver.

The remaining precipitate, which is white, is entirely soluble in ammonia (NH_4O), which proves it to be entirely the undecomposed chloride of silver ($Ag\ Cl$). Now, had subchloride of silver ($Ag_2\ Cl$) been present, the precipitate would not have been at all soluble in nitric acid ($HO.\ NO_5$), and would have left a precipitate with ammonia (NH_4O) instead of being entirely dissolved.

It is unnecessary to go into the action of light on nitrate of silver ($AgO.\ NO_5$) alone, as this is of the same nature as that on chloride of silver ($Ag\ Cl.$).

It appears then that light acting on chloride ($Ag\ Cl$) or nitrate of silver ($AgO.\ NO_5$) tends to reduce them to the metallic state; but when they are together it will be seen that though a similar result, viz., the reduction of metallic silver is obtained, the process is somewhat different.

The chloride ($Ag\ Cl$) being more sensitive than the nitrate ($AgO.\ NO_5$) is first reduced to metallic silver and free chlorine ($Ag + Cl$); the free or nascent chlorine (Cl) from this immediately decomposes an adjacent atom of nitrate of silver ($AgO.\ NO_5$), to chloride of silver and nitric acid ($Ag\ Cl + HO.\ NO_5$), of which the chloride of silver ($Ag\ Cl$) is in turn decomposed, thus liberating fresh chlorine. In this manner a series of decompositions and recompositions is carried on, the nitrate of silver ($AgO.\ NO_5$) serving to keep up the reduction begun with the chloride ($Ag\ Cl$).

That this is really so, will be evident if we add a little chloride of sodium ($Na\ Cl$) to a solution of nitrate of silver ($AgO.\ NO_5$), thus obtaining chloride of silver ($Ag\ Cl$) in suspension in the excess of nitrate ($AgO.\ NO_5$). This is a close approximation to the state of a proof before exposure. On examining the solution after exposure to the sun's rays, no free chlorine will be detected, but free nitric acid will be detected by the usual tests. This experiment shews that the chlorine as fast as it is liberated from the chloride ($Ag\ Cl$) decomposes the solution of nitrate ($AgO.\ NO_5$), liberating nitric acid ($HO.\ NO_5$). This shews us the use of the excess of nitrate of silver ($AgO.\ NO_5$) present in our proofs; it supplies fresh silver to the nascent chlorine, and we all know how energetic is the action of any substance in its nascent state.

That chloride of silver ($Ag\ Cl$), in contact with nitrate ($AgO.\ NO_5$), is more sensitive than either alone will be evident if we place moist pulverized chloride ($Ag\ Cl$) and nitrate of silver ($AgO.\ NO_5$) on a glass plate in contact at one edge. It will be seen that the parts where the salts are in contact darken much more rapidly than either of the salts alone.

We know that the colour of the silver as thus precipitated is of a dull grey, whereas our prints are of all hues from red to brown. It will be evident then that we have not considered all the conditions which affect the proof in this reasoning; it remains to search for this in the organic compounds or sizes always used in practice.

If we add solution of nitrate of silver ($AgO.\ NO_5$) containing chloride ($Ag\ Cl$) in suspension to solutions of starch, gelatine, and albumen, in the latter solution alone is a precipitate produced.

But, on exposing these three solutions to light, in all of them, but especially in the latter, is obtained a fine reddish brown precipitate, similar in colour to that of a print when it leaves the frame.

In fact, we have here fulfilled the exact conditions of one of our ordinary prints. On examining this precipitate it is found to consist of metallic silver, of undecomposed chloride of silver ($Ag\ Cl$) in excess, and of a certain compound which, when burnt with black oxide of copper (CuO), yields carbonic acid (CO_2); with hydrate of potash ($KO.\ HO$) yields ammonia (NH_4O) and before the blowpipe gives indications of silver.

This a sure test of organic matter in combination.

It is clear then that the nitric acid ($HO.\ NO_5$) set free by the decomposition of the nitrate of silver ($AgO.\ NO_5$), which I spoke of before, decomposes a portion of the organic matter which unites with some of the silver, forming a coloured organic salt of silver.

This result is most important, as it shews us that the tone, so to speak, of our proof is due to minute quantities of organic salts of silver.

It would be important to know whether the organic salts of silver are due to the decomposition of the nitrate ($AgO.\ NO_5$), or chloride of silver ($Ag\ Cl$).

By conducting the same experiment separately with nitrate ($AgO.\ NO_5$) and chloride of silver ($Ag\ Cl$) we find the sizes produce with chloride of silver ($Ag\ Cl$) a very minute quantity of precipitate, as compared to what they do with the nitrate.

This is another proof of the value of excess of nitrate of silver ($AgO.\ NO_5$) in our proofs. It not only furnishes material to carry on the reduction of silver begun in the chloride of silver ($Ag\ Cl$) but it supplies the same to form the beautiful organic salts of silver.

To sum up then the information obtained as to the action of light on a common print.

The chloride of silver ($Ag\ Cl$) is reduced to its elements, ($Ag + Cl$); the nascent chlorine decomposes the adjacent atom of nitrate ($AgO.\ NO_5$) into chloride and nitric acid ($Ag\ Cl + HO.\ NO_5$). Again, this atom of chloride of silver ($Ag\ Cl$) is reduced, and liberates chlorine, by which a series of decompositions and recompositions is carried on. Further, the free nitric acid ($HO.\ NO_5$) decomposes an adjacent atom of the sizing, forming thereby an organic compound of silver, the nature of which I cannot attempt to explain. Of these, the metallic silver confers a neutral grey tint, and the organic silver salts confer the colouring.

The proof now evidently consists of two distinct parts, viz., the parts altered by light, and the portions unacted on. The former consisting of metallic silver and organic salts of silver, and the latter of chloride of silver ($Ag\ Cl$) in contact with excess of nitrate.

It is evident, then, that as the proof has already been altered in parts, by the action of light, the parts as yet unacted on, that is the white parts, would, if exposed to light, speedly alter, and the whole proof would become of one uniform tint. To prevent then this change, we must find some agent that will render those portions unacted on, unalterable by light, either by completely dissolving out the silver salts, or so altering their nature as to render them insensitive; at the same time it must not darken the white parts, nor greatly alter the colour of the dark parts; and lastly, must leave nothing on the print capable of inducing any change in course of time.

A reagent possessed of so many properties is not to be found in a hurry, and many years elapsed after the discovery of the method of sun printing before any certain method of fixing was discovered. Indeed, no method of fixing has yet been discovered that is perfectly free from objection. The reagents proposed for this purpose are few in number; they are *water*; then cyanide of potassium (KCy), ammonia (NH_4 O), and hyposulphite of soda (NaO. S_2O_2).

The action of fixing agents may I suppose be divided into two heads, viz., their action on the two different parts of the proof, the white and the coloured parts. Were it possible, it would of course be as well to use some agent which had no action on the coloured parts of the proof; but unfortunately, all the agents as yet proposed have a rather disagreeable action on them. Of these agents water, in so far as it can be used, is a very important one. You will remember that an excess of nitrate of silver (AgO. NO_5) is present in all proofs; also a certain amount of free nitric acid (HO. NO_5) and nitrate of soda (NaO. NO_5) are present. All these are soluble. If, then, on taking the print out of the frame we wash it thoroughly, we may hope to remove the greater portion of them. Now this is a very important thing to do, for several reasons.

(*a*) By the removal of these, the only salt left in the white portions is the chloride of silver (Ag Cl), and, therefore, instead of introducing three salts into the fixing bath, we introduce only one. The reaction therefore will be of a more definite and less intricate nature; it is therefore easier to control the process.

(*b*) In point of economy it is very important; for first, by the removal of the nitrate of silver (AgO. NO_5) we have but one salt, the chloride (Ag Cl) left for the fixing agent to deal with, which will cause a great saving of the latter. Secondly, the nitrate of silver (AgO. NO_5) is extracted in considerable quantity, and in a form in which it is not difficult to apply it again for further use. This causes a very great saving also.

I suppose, then, that the advantages of using water as a fixing agent are so great that all operators would be inclined to use it. It exercises, however, rather an important action on the coloured parts of the proof of a plain or unalbumenized paper.

We all know that gelatine, after prolonged immersion in cold water, combines with part of the water or becomes hydrated; and that starch does the same pretty quickly in hot water. If a print, then, on plain paper of English make (starch sized) be immersed in hot water, the starch will speedily become hydrated; and it is found that the hydrates of the organic silver salts, formed during exposure, are of a disagreeable red. The same thing occurs with a French (gelatine sized) print immersed in hot water, or after prolonged immersion in cold water.

In albumenized prints, the albumen is always reduced to the insoluble form in the sensitizing; so that water has no effect on its coloured parts. Supposing then that the print has been well washed, the nitrates of silver (AgO. NO_5) and soda (NaO. NO_5) will have been removed from it, and there is but chloride of silver (Ag Cl) for the fixing agent to act on.

Considering the fixing agents generally, we see that they are all three of an alkaline nature. Now, we know that alkalies possess the power of hydrating such substances as usually form the sizes of our papers, such as starch, gelatine, and albumen; it follows then that on immersing a print in any of them, the organic salt of silver will speedily be hydrated, and it is to this hydration that much of the change in colour or tone, noticed on placing the print in the fixing bath, is owing.

To consider the fixing agents in detail. Everyone knows that chloride of silver ($Ag\,Cl$) is soluble in ammonia ($NH_4\,O$); accordingly, this was one of the first fixing agents proposed. If three sheets, viz., starch, gelatine, and albumenized papers be sensitized as usual, exposed, and washed to remove nitrate of silver ($AgO.\,NO_5$) and nitrate of soda ($NaO.\,NO_5$), and then analyzed, it is found that from the first two the whole of the silver is dissolved, but not entirely from the albumenized paper. The same thing will occur if hyposulphite of soda ($NaO.\,S_2O_2$) be used instead of ammonia (NH_4O). This shews why it is so difficult to preserve the whites of albumenized paper pure, for, as a little sensitive salt of silver is still left in the whites, they are apt to discolour slightly on exposure to light.

The action of ammonia (NH_4O) on the coloured parts of the print is peculiar. A portion of it combines with the organic silver salts as they become hydrated, and a very disagreeable red tint is produced. This has led to the disuse of ammonia (NH_4O) as a fixing agent.

Cyanide of potassium (KCy) acts differently from ammonia (NH_4O) on the white parts of the proof. In this case, the chloride of silver ($Ag\,Cl$) is decomposed thus—

$$\underbrace{Ag\,Cl}_{\text{chloride of silver}} + \underbrace{K\,Cy}_{\text{cyanide of potassium}} = \underbrace{Ag\,Cy}_{\text{cyanide of silver}} + \underbrace{K\,Cl}_{\text{chloride of potassium}}$$

Now cyanide of silver ($Ag\,Cy$) is soluble in water, and may be removed by repeated washing. This solvent action of cyanide of potassium ($K\,Cy$) appears to be perfect, even with albumenized paper. Unfortunately, it also decomposes the coloured organic portions of the proof into cyanide of silver ($Ag\,Cy$), though with great difficulty; so that unless great care be taken in using it, there is danger of its effacing the whole picture.

The most important then of the fixing agents, and the one in general use, is hyposulphite of soda ($NaO.\,S_2O_2$). The reactions of this salt are frequently very complicated. Everyone who has looked through the article on sulphur in any of our elementary works on chemistry, must have remarked the large number of acids formed by the union of sulphur and oxygen, and the rather anomalous proportions in which these elements are combined. They are seven in number, and are known as—

Hyposulphurous	S_2O_2	Sulphurous	$S\,O_2$
Pentathionic	S_5O_5	Dithionic or Hyposulphuric	S_2O_5
Tetrathionic	S_4O_5	Sulphuric	$S\,O_3$
Trithionic	S_3O_5		

They are characterised by their great instability, and their tendency to separate into sulphur (S) and sulphuric acid ($HO.\,SO_3$).

The hyposulphite of soda ($NaO.\,S_2O_2$) is used in a more or less concentrated solution. On adding nitrate of silver ($AgO.\,NO_5$) drop by drop to a solution of hyposulphite of soda ($NaO.\,S_2O_2$), a white precipitate is noticed of hyposulphite of silver ($AgO.\,S_2O_2$), by the reaction—

$$\underbrace{NaO.\,S_2O_2}_{\text{hyposulphite of soda}} + \underbrace{AgO.\,NO_5}_{\text{nitrate of silver}} = \underbrace{AgO.\,S_2O_2}_{\text{hyposulphite of silver}} + \underbrace{NaO.\,NO_5}_{\text{nitrate of soda}}$$

This precipitate immediately unites with two atoms of hyposulphite of soda ($NaO.\ S_2O_2$) to form double hyposulphite of silver and soda (($AgO.\ S_2O_2 + 2(NaO.\ S_2O_2)$)), a beautiful white crystalline salt, very soluble in water or in solution of hyposulphite of soda ($NaO.\ S_2O_2$), and undergoing no change in the light. The same reactions take place with chloride of silver ($Ag\ Cl$). If then a single proof be immersed in a new solution of hyposulphite of soda ($NaO.\ S_2O_2$), the above reactions take place, and experience shews the fixing to be excellent, and the proof, if well washed, is very durable. But if the solution be not strong enough to form and dissolve the double salt, or if the print is not agitated in the bath to promote its formation and solution, another double hyposulphite of silver and soda ($AgO.\ S_2O_2 + NaO.\ S_2O_2$) insoluble in water, will be formed, instead of the soluble one. This one is not affected by light in the dry state, but in contact with water, it is readily decomposed into hyposulphite of silver ($AgO.\ S_2O_2$) and of soda ($NaO.\ S_2O_2$). Now, hyposulphite of silver ($AgO.\ S_2O_2$) is such an unstable salt that it cannot exist except in combination. Immediately then that it is isolated, the reaction,

$$\underbrace{AgO.\ S_2O_2}_{\text{Hyposulphite of silver}} + \underbrace{HO}_{\text{water}} = \underbrace{AgS}_{\text{sulphide of silver}} + \underbrace{HO\ SO_3}_{\text{sulphuric acid}}$$

takes place; further, the nascent sulphuric acid ($HO.\ SO_3$) decomposes an adjacent atom of hyposulphite of soda ($NaO.\ S_2O_2$) thus—

$$\underbrace{NaO.\ S_2O_2}_{\text{hyposulphite of soda}} + \underbrace{HO.\ SO_3}_{\text{sulphuric acid}} = \underbrace{NaO.\ SO_3}_{\text{sulphate of soda}} + \underbrace{HO}_{\text{water}} + \underbrace{SO_2}_{\text{sulphurous acid}} + \underbrace{S}_{\text{sulphur}}$$

Of these, sulphide of silver (AgS) and sulphur (S) are insoluble, and are, consequently, precipitate.

Whenever then a print is immersed in the fixing bath under such conditions that the hyposulphite of silver ($AgO.\ S_2O_2$) is not transformed into the soluble double salt as fast as it is formed, it follows from the above reactions that there will be a tendency to deposit both sulphide of silver (AgS) and sulphur (S) side by side on the proof, and the sulphur thus deposited will act as an element of change, and the metallic silver will gradually under the influence of light and moisture combine with it, so that the print will fade, and present that faded yellow appearance which is so common among prints done a few years ago. It appears then that to prevent this, only a small number of prints should be fixed in the bath, proportioned of course to its strength, and that when first put in they should be continually stirred about, to promote the formation of the soluble double salt. Further, that the bath should not be exposed to the light; for, it must be remembered, that, under the influence of light, when in contact with water, the insoluble double hyposulphite of silver and soda ($AgO.\ S_2O_2 + NaO.\ S_2O_2$) is decomposed.

Lastly, the bath should be kept as far as possible in a normal condition, *i.e.* no acids should be added to it, as these invariably decompose a portion. This shews the importance of the preliminary washing of the proof, for, by this means, we remove any free nitric acid ($HO.\ NO_5$) formed by the action of light on the proof.

Further, the bath should be pretty strong, and the print must not be long in it, as the bath possesses the same property, that cyanide of potassium ($K\ Cy$) has, of dissolving the coloured portions of the proof, though to a much smaller extent.

It remains only to speak of this action on the coloured parts of the print. All who have seen some of the earlier prints will remember the disagreeable red tone on the coloured parts, which I explained was owing to the hydration (under the alkaline influence of the fixing agent) of the organic silver compounds. It was a desirable thing then to find some method of restoring the tone to the pictures. It was soon discovered that fixing baths which had been used for a long time, ("*old baths,*" in fact), possessed this property of toning, from every tone of red-brown to a blue-black. And it was found that the addition of minute portions of various substances, such as acetic acid ($HO.\ \bar{A}$) to the fixing bath, gave this property to a new bath. From what I have shewn above, it will be evident that these methods cannot be good or durable. It has been shewn that this toning property of old baths arises from their utter decomposition, from the formation of several of the rarer compounds of sulphur and oxygen, the thionic acids which I spoke of before. This arises from the presence of sulphurous acid (SO_2) in the bath, produced as I explained above; for whenever sulphurous acid (SO_2) and hyposulphite of soda ($NaO.\ S_2O_2$) come together, the following reaction takes place,

$$\underbrace{2\,(NaO.\ S_2O_2)}_{\text{hyposulphite of soda}} + \underbrace{3\ SO_2}_{\text{sulphurous acid}} = \underbrace{NaO.\ S_3O_5}_{\text{trithionate of soda}} + \underbrace{NaO.\ S_4O_5}_{\text{tetrathionate of soda}}$$

The toning is principally owing to the latter, but as I said before, all the thionic acids are very unstable.

It would not be worth our while to go into all the complicated reactions of old baths, as they are never used now. Suffice it to say that the prints of a few years back have, to a great extent, faded from the deposition of sulphur on the print.

A more durable and equally agreeable method has been fortunately discovered. I mean the toning with salts of gold, as is now usual. For this purpose, the terchloride of gold ($Au\ Cl_3$) is used in solution, either with the hyposulphite of soda ($NaO.\ S_2O_2$) solution, or in an alkaline bath, before fixing. There is a great disadvantage in the former method, from the great instability of the hyposulphite of soda ($NaO.\ S_2O_2$). The chloride of gold ($Au\ Cl_3$) of commerce is generally acid, and the addition of free acid to the fixing bath generally leads to its decomposition, as I before shewed, and a considerable quantity of the gold is deposited in the bath, as a black sediment of tersulphate of gold (AuS_3), and is thus wasted.

It is therefore a much better, and also a simpler plan to dissolve the chloride of gold ($Au\ Cl_3$) in some feebly alkaline solution, say, carbonate of soda ($NaO.\ CO_2$), and use it after the washing of the print on removal from the frame. In this case, gold is deposited on the coloured portions of the print, and protects them from the action of the fixing solution; at the same time that it gives them a more or less agreeable tone. Another important point is that, any free acid on the paper which would otherwise have found its way into the fixing bath is here neutralized. There is then a great advantage in the use of alkaline gold toning baths.

The print, being toned sufficiently, is fixed, and washed very thoroughly to remove all traces of hyposulphite of soda ($NaO.\ S_2\ O_2$). On this latter washing depends much of its durability, for of course if any appreciable quantity of hyposulphite of soda ($NaO.\ S_2\ O_2$) be left on the print, it will in a damp atmosphere undergo all the decompositions explained above, and eventually fade.

To sum up then, a print before exposure consists in general of chloride of silver, with excess of nitrate of silver; and, when albumenized paper is used, of albuminate of silver, in contact with certain organic substances or sizes, which appear to be inert before exposure, and nitrate of soda ($NaO.\ NO_5$), sustained by a neutral stratum of cellulose.

On exposure, the chloride of silver ($Ag\ Cl$) being the most sensitive, is reduced to metallic silver. The nascent chlorine converts an adjacent atom of nitrate of silver ($AgO.\ NO_5$) into chloride ($AgCl$), which is in turn reduced to metallic silver, and free nitric acid ($HO.\ NO_5$) liberated. This deposit of silver appears to be of a grey colour. The organic matter of the size, partly perhaps from the presence of free nitric acid ($HO.\ NO_5$), is decomposed, and an organic salt of silver of more or less red colour results; to which is owing the tone of our proofs.

The nitrate of soda ($NaO.\ NO_5$) takes no apparent part in these reactions. The soluble portions are now removed by washing, and the print is immersed in the fixing bath, when the undecomposed chloride of silver ($Ag\ Cl$) from the whites of the proof is dissolved out as double hyposulphite of silver and soda $[2\ (NaO.\ S_2\ O_2) + AgO.\ S_2\ O_2]$, and the coloured organic silver salts become hydrated under the alkaline influence of the fixing agent. The proof, after repeated washing, is considered finished.

In the finished proof, in the whites if on albumenized paper, a very small quantity of silver salt appears to remain, which will lead to a slight discolouration eventually. The coloured parts appear to consist of a basis of grey metallic silver, with various organic salts of silver in different degrees of hydration, to which the colour of the print is owing; and in addition, a very small deposit of metallic gold, to which the fine tone is owing.

In the whole of this paper I have said nothing of the molecular arrangement of the particles of reduced metal, because as far as I know, no researches have been made in this particular department; though I have no doubt that much of the variety of tone is, or at any rate may be owing to this cause.

For instance we know that very many salts when pulverized appear white, whilst when crystallized or in strong solution, many present very striking colours. We also have examples of this in cases of dimorphism and allotropy. The iodide of mercury in the rhombic form is of a salmon yellow, and in the octohedral form, of a bright scarlet.

We know also, that whereas diamond is transparent, common charcoal is black and opaque; common phosphurus also is white, whilst amorphous phosphorous is red. Other examples could easily be found to warrant the belief that the colour depends on the molecular structure of the deposited metal.

It only remains then to inquire if the proof, as thus produced, is durable. It would appear, that if carefully fixed, that is to say, if all sensitive salts are removed, and then all traces of the fixing solution removed, it is very durable.

But, it frequently happens, that a print very carefully prepared will fade. One source of this is to be traced to the solution used for mounting.

Starch, ordinary gum, and flour paste, are commonly used for this; but they are all open to objection, being organic compounds of the sugar series, and all more or less capable of being converted, in a damp atmosphere, into acetic ($HO.\bar{A}$) or other similar acids, which will by degrees set up a decomposition in the proof, which will lead to its fading. Gelatine, if perfectly pure and fresh, seems to be the only thing perfectly safe, and perhaps rice water.

But another source of danger is in the atmosphere. The atmosphere of towns, such as London, contains traces of hydrosulphuric (HS) and sulphurous acids (SO_2), and other deleterious gases, with a variable proportion of moisture. These, especially the gases containing sulphur, are very hurtful to photographic prints, the sulphur (S) combining perhaps with the silver (Ag), to form the dirty yellow sulphide of silver (AgS).

It is evident then that a photographic print is a very delicate object; but I believe, that with due care, they are very durable.

When it is considered that of all the silver actually used in the production of a print, but 5 per cent. goes to the formation of the actual image, that is to say, 95 per cent. is lost, it will be seen how exquisitively beautiful and delicate must be the nature of the chemical action throughout, and how exceedingly difficult to investigate.

I think it is a matter of great importance to every photographer to be acquainted with the nature and action of the materials he uses, and certainly to us, who make it, as it were part of our profession, because we cannot otherwise be convinced of the durability of our results, nor of the advantage and economy of the particular process we are using.

In a discussion which followed the reading of this paper,* Captain Schaw remarked that though the views adopted by Lieutenant Cunningham differed from those advanced by many English chemists, among whom was Mr. Hardwich, they certainly seemed to have the advantage in point of simplicity. The theory generally adopted hitherto was that the violet tint conferred on chloride of silver ($Ag\ Cl$) by exposure to light, resulted from the formation of a subchloride ($Ag_2\ Cl$), which was the chief colouring matter in the photographic image before fixation. The chief objection to the theory now proposed seemed to him to be that cyanide of potassium ($K\ Cy$) completely bleaches the coloured portions of a print, which, according to this theory, should consist of metallic silver with organic salts of the same metal. If then the organic salts were dissolved by the cyanide, the paper should be left of a grey tint, viz., the tint of metallic silver.

Lieutenant Cunningham objected to this as *inconclusive*, unless it could be shewn that silver, in the molecular state in which it exists on a print, was insoluble in cyanide of potassium ($K\ CY$), or at any rate, unaffected in colour under its influence (which might be supposed catalytic).

Captain Scott agreed in the view that though metallic silver in the ordinary condition was insoluble in cyanide of potassium ($K\ Cy$), the silver in the condition in which it exists in a print might be soluble, but it did not seem to him satisfactory to attribute the entire fading of some prints to an union between the silver and sulphur, for sulphide of silver is of a brown black.

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* This paper was originally read at the Royal Engineer Establishment, Chatham.—Ed.

Lieutenant Cunningham said that in faded proofs analysis reveals the presence of sulphur and of silver; and though sulphide of silver (AgS) as precipitated from solutions is black, it does not follow that sulphur and silver combining under the influence of light should be black.

Captain Schaw thought the yellow appearance of a faded print to be rather owing to separation of free sulphur on the surface than to a chemical union.

Lieutenant Trotter said that the practice at Addiscombe Military College had been different, as regards fixing, to the method recommended in this paper. It was *not* usual to wash the paper before fixing; and the fixing and toning were generally performed in one bath, which was used over and over again till a large quantity of sediment appeared. Lieutenant Trotter had in his possession some proofs printed in this manner which were in a very good state of preservation.

Lieutenant Cunningham stated that the danger of such proceeding would be evident from what had been said; indeed, particular stress had been laid on the fixing process in this paper, owing to the writer's recollection of the method used there, besides, those in Lieutenant Trotter's possession had not stood the test of time.

Captain Schaw said, that though sulphur had been proved injurious to the permanency of a print, he had heard of a method of toning by sulphur only, which was stated to be very durable, but had not yet come into public notice.

NOTE.—With a view to determine whether the result of the action of light on a common print was as stated in this paper, Capt. Schaw made the following experiments:—

A print was prepared, exposed, and fixed by cyanide of potassium till the coloured parts (which should consist of silver and organic salts of silver) were bleached.

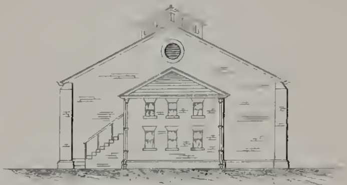
1. To see whether the *silver* (if existing) had merely been bleached, *i.e.* so altered in molecular structure as to change its grey tint for a white, the paper was washed to remove cyanide of potassium and soaked in dilute nitric acid ($HO. NO_5$), which would have dissolved any free silver remaining; solution of chloride of sodium ($Na\ Cl$) added to this gave no precipitate. Evidently the silver, if such existed on the paper, had been all removed by the cyanide.

2. As, however, it was doubtful whether silver were soluble in cyanide of potassium ($K\ Cy$), a small quantity was precipitated by a strip of copper from a nitrate solution in a fine state of division, and digested with cyanide of potassium ($K\ Cy$) in solution, which was afterwards separated by filtration; the clear liquid was evaporated to dryness. The solid thus obtained would (if silver were soluble in the cyanide) consist of cyanide of silver ($Ag\ Cy$), with excess of cyanide of potassium. This remainder was ignited in a crucible to get rid of cyanogen ($C_2\ N = Cy$), then dissolved in nitric acid ($HO. NO_5$), and tested with chloride of sodium, which gave no precipitate; thus shewing that silver was absent, and therefore not ordinarily soluble in cyanide of potassium.

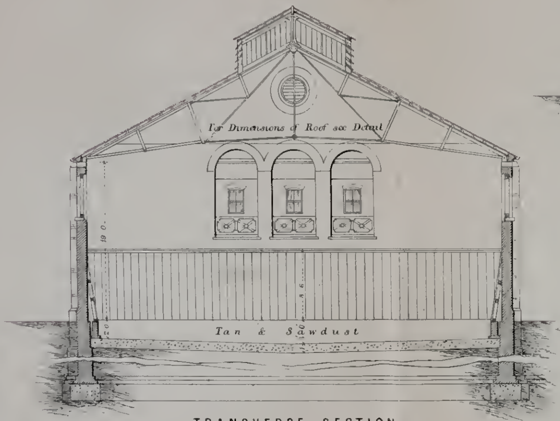
It will be evident, nevertheless, that these two experiments do not conclusively shew that metallic silver is not the result of the action of light on chloride of silver; for it has not been shewn that silver *in the molecular state in which it is reduced on a print* is insoluble in cyanide of potassium, in presence of chloride ($Ag\ Cl$) and organic salts of silver.

A. CUNNINGHAM, Lieutenant,
Royal Engineers.

CAVALRY RIDING SCHOOL.



END ELEVATION



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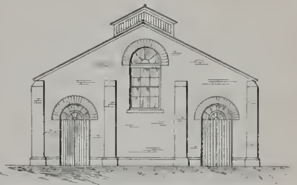

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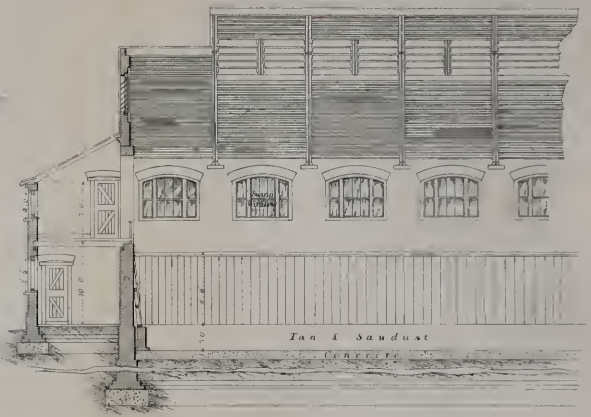

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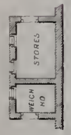
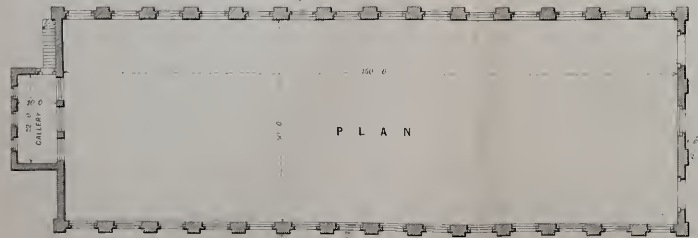
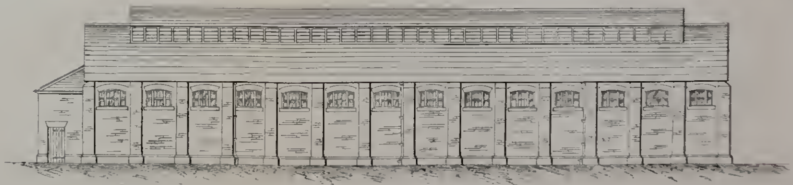




PLAN



FRONT ELEVATION

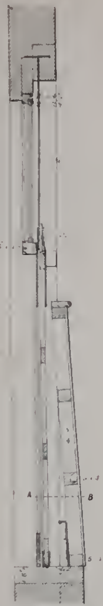
Scale to Plan & Elevations, 30 feet = 1 inch.

Scale to Sections, 15 feet = 1 inch.

C Moody Litho [illegible]

RIDING SCHOOL.

DETAILS.



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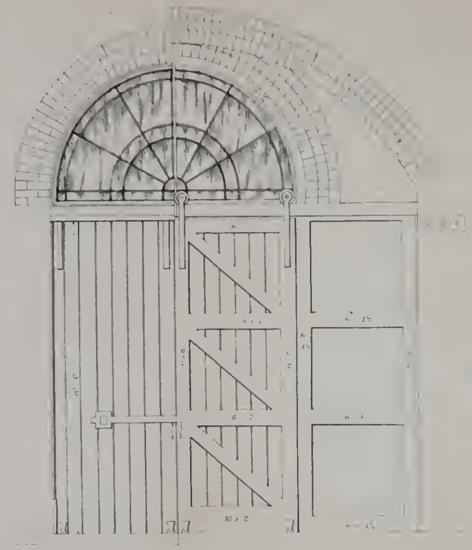
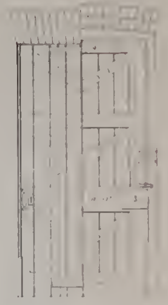
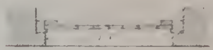


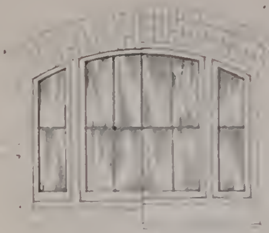
EXTERIOR & INTERIOR
ELEVATION OF ENTRANCE DOORS



EXTERIOR & INTERIOR
ELEVATION OF DOOR TO GALLERY

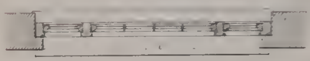


PLAN

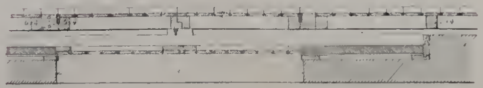


EXTERIOR & INTERIOR
ELEVATION OF WINDOWS

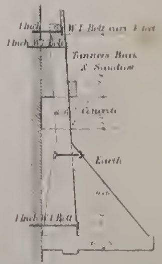
SECTION



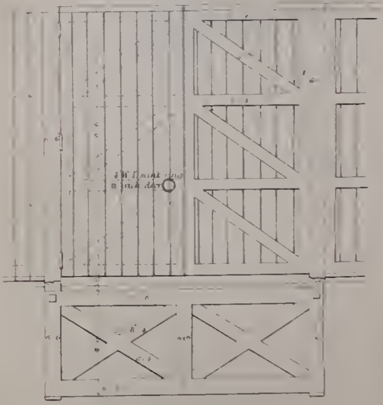
PLAN



PLAN OF ENTRANCE DOORS &
DOORS OF GUARD BOARDING (ON LINE A B)



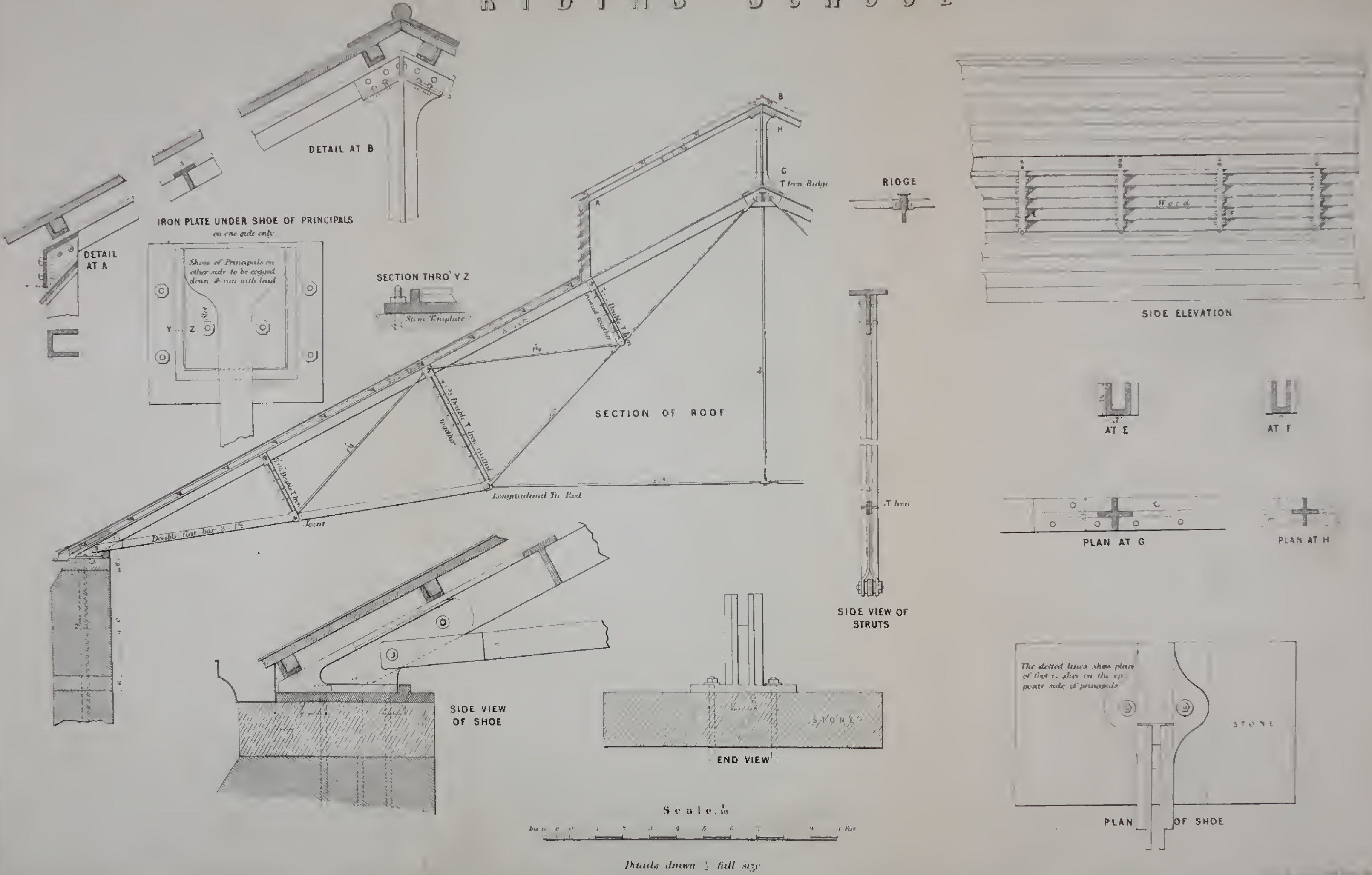
SIDE ELEVATION OF HANGING POSTS
FOR DOORS OF GUARD BOARDING



ELEVATION OF DOORS &c IN GUARD
BOARDING ACROSS ENTRANCE DOORWAYS

Scale 4 Feet 1 Inch

RIDING SCHOOL



Scale $\frac{1}{16}$

Details drawn ½ full size

PAPER XI.

MILITARY RIDING SCHOOLS.

In any large barrack where mounted troops are quartered, a riding school must necessarily be provided.

There has hitherto been a great variety in the size and mode of constructing buildings for this purpose.

For instance the old riding school of the Cavalry Depôt at Maidstone, which was constructed of wood, was only 100 feet long by 40 feet wide; that at Canterbury was 120 feet long by 40 feet wide; whilst the more modern schools in the new permanent barracks at Aldershot are 180 feet long and 60 feet wide.

In deciding upon the best dimensions for a riding school, the following requirements must be attended to, viz.:—

1. The length should be three times the breadth.
2. The height should be sufficient to admit of the lance being carried.
3. Whilst it will admit of a sufficient number of officers, non-commissioned officers, or men, being exercised in each "ride," the cost should not be out of proportion to the advantages accruing from its size.
4. A gallery should be provided to admit of the inspection of the rides by superior officers.
5. There should be a store attached to contain leaping bars, practice posts, &c.

It may be added that a clock is desirable in order to regulate the length of the time for the rides, and gas fitments should be provided in order that the school may be made available for fencing and single stick practice in the evenings.

To fulfil these requirements the accompanying design was prepared in the office of the Inspector General of Fortifications, and the general dimensions upon which it is based were approved by cavalry officers of great experience.

A new riding school has been constructed at Maidstone, in accordance with this design, at a cost af £2,693 (by special contract). It has been in use since last April, and has been found to answer very well.

A similar school is to be built this year at Canterbury, so that there will be one upon this plan at each of the two Cavalry Depôt stations in this country.

An open manége is required, in addition to a riding school, in barracks for mounted troops: it should be 180 feet long, and 60 feet wide; well drained, and covered with fine gravel.

It is necessary for horses to be exercised in the open manége as well as the riding school, in order to prepare them for working steadily in the field with various objects in sight, which do not occur to distract their attention in the school.

C. B. EWART, Major, R.E.,
Assistant Q. M. General.
22nd July, 1862.

PAPER XII.

PRACTICAL SUGGESTIONS RELATIVE TO SURVEYING INSTRUMENTS.

By LIEUTENANT NEWSOME, R.E.

1. Considerable advantage will be found in removing the unsilvered portion of the smaller or fixed mirror in the sextant, but more particularly in the pocket sextant, where, owing to its construction, light is to a great degree excluded. The plain portion of the glass plays no part in the instrument, but is always getting dirty and impeding vision, it is extremely difficult to clean in the pocket sextant, and is a source from whence the edge of the silvered portion frequently receives injury in the attempt to remove dirt. No one, I think, trying this suggestion, would ever have an instrument of the old make again, the increased clearness ensures the most perfect alignment and contact of objects, and little inconvenience is felt from rain or spray. I think also it is desirable that the glass of the mirrors should be as thin as possible, as the theory of the sextant is true only with respect to polished plane surfaces. What amount of refraction may occur by placing a plate of glass before it, or what error it may occasion, I have not investigated, but it is evident some must exist, especially where, as is frequently the case, very thick plate looking-glass is used. In the sextant made for me with the thinnest glass procurable, I have noticed less difference between the sum of two angles taken to an intermediate object, and the whole angle observed at once, than used to be the case with an instrument having thicker glass.

2. Magnetic surveying instruments constructed for the latitude of London, when taken to the southern hemisphere, are often nearly useless from the different effect of the dip. A needle, to swing level in London, must have the south end, before being magnetized, heavier than that intended for the north, so that when magnetized and subjected to the attraction causing the dip, the balance may be restored; this needle, taken to a southern latitude, not only loses this balancing power, but also has the southern dip added to the already existing preponderance, and in an instrument requiring to be set level like a theodolite, often drags on the plate and will not swing; this might be readily obviated by having the agate cap to move in a slot in the centre of the needle with a binding screw like proportional compasses—a small slot would suffice.

3. At very few stations is the Royal Engineer Office provided with a standard chain, nor perhaps is it necessary that a very perfect or expensive instrument should be provided; at the same time a certain amount of uniformity in all

surveys is most desirable, and for an exceedingly small sum every station might be provided with such a standard as I propose, which would ensure every chain used in surveying being within $\frac{1}{4}$ of an inch of its proper length. The chain I suggest should be made of flat crinoline steel $\frac{1}{2}$ an inch in width and $\frac{1}{20}$ to $\frac{1}{30}$ of an inch in thickness, formed in 1 foot lengths, turning on a rivet. Small and cheap yard measures are at present made of this fashion. The cost of such a chain could not exceed five shillings, and would last practically for ever. It should never be used but under the eye of an officer, and then simply stretched on level ground to give the exact distance for lines to be cut on stones, let into the earth previously at either end of an approximately correct line. These should be laid down at every convenient position in a station for constant reference, where the chain is liable to be used. The trouble and difficulty of setting out 100 exact feet correctly are, without some such means, too great to induce most officers, or others engaged on minor surveys, to pay any very great attention to this matter, and without considerable care, it cannot at present be done. With a well-made standard yard it is not easy to set out 100 feet to the $\frac{1}{8}$th part of an inch, but when no access can be had to such a measure, and ordinary ones have to be depended upon, much greater error is liable to occur.

W. NEWSOME, Lieutenant,
Royal Engineers.

Woolwich, 12th May, 1862.

PAPER XIII.

ON THE APPLICATION OF IRON TO DEFENSIVE WORKS.

By CAPTAIN INGLIS, Royal Engineers.

Having had the advantage of witnessing most of the interesting and valuable experiments which have been made in recent years, with the view of ascertaining the resistance offered by iron to the battering of heavy ordnance, and having taken great interest in all that affects the question of the adaptation of iron to the general purposes of defence, I was asked, in the course of last winter, to prepare a paper on the subject, to be read to the Corps at Chatham. That paper was intended to give something like a connected history of the question as it then stood. And as in collecting information for that purpose some matter was got together which, at the present day, cannot fail to be interesting to many of my brother officers, I have ventured to resume the subject in this volume of the Corps Papers.

The first object of the Chatham Paper, above referred to, was to ascertain whether—looking at the rapid development of the science of artillery, which is now going on both in our own country and in all other great states—we are, for the future, to make any, and if any, what, use of iron in our works of fortification generally; and by a very brief consideration of recent experiences, it became apparent that, for the future, iron must become a very important material indeed to the Military Engineer.

It was thought that no one who has witnessed the increasing precision of modern cannon, and the facilities which recent inventions have given us for building guns of almost any size and strength, together with the growing capabilities of great armies and fleets, could fail to see that the materials hitherto used in our works of fortification, are about to be completely overmatched by the weapons of offence.

One is tempted now to go further than this, and say that even before the recent improvements in artillery weapons, masonry was quite unequal to the purposes for which it was often used. It had only to be seen to be destroyed: and it can scarcely be said that the art of fortification was successfully practised while such conditions existed.

The question of the application of such a material as iron to our defensive works may appear novel, and even startling, to many of us; yet it is not quite so new a question as we might suppose.

Many eminent scientific men have looked forward to the time, when some material of greater resisting power than stone would be used in works of fortification.

One of the most notable instances of this foresight is that of Paixhans, who, writing in 1829, devoted a considerable part of his valuable work styled, "Force et Faiblesse Militaires de la France" to a discussion of the use of iron in fortification. He did not see exactly how it could best be applied, but still he saw that sooner or later it must be used, and he argued by analogy as it were in its favour; he asked why, when a man wears a cuirasse to ward off a certain blow, should it be an absurd idea to make a wall wear one so as to be proof against another blow, and whether a fortification of iron would be more strange than bridges of iron, ships of iron, factories and churches of iron, and above all roads of iron; and he said, what material can be more suitably employed in striving to resist iron projectiles than iron itself? This author also mentions that Gustavus Adolphus proposed to fortify with blocks of iron, and that Darcon wished to plate with iron his floating batteries against Gibraltar. And General Totten clearly contemplated the facing a whole work with iron, indeed the construction of works of iron only, whenever the necessity should arise.

And if more than 30 years ago Paixhans, a Frenchman, could thus argue in favour of iron from what he saw about him in his country, surely we in England in 1862 see enough around us to excite surprise that fortification is about the only branch of engineering in which the use of iron has until just now been utterly neglected. We, who raise in Great Britain alone as much crude iron as all the other countries of the world put together, and more than four times as much as either of the next great producers, namely, France and the United States—we, whose make of pig iron in the last 40 years has increased ten-fold, and now has arrived at the enormous figure of nearly 4,000,000 tons per annum, representing a market value of upwards of £12,000,000 sterling—we, who not only have undertaken with the greatest success, in our own country and in our dependencies, gigantic works in iron, but have executed with our own iron, and with our own skill and enterprise, most of the largest works in foreign countries—we, who in fact may almost be said to have raised ourselves to the highest eminence in commerce and manufacture, in proportion as we have advanced in the production and conversion of iron—surely we have a right to think of using that very material extensively in the defence of our country, if we can prove that it is more suitable for the purpose than any other that can be found.

It is said above that many other able men beside Paixhans have in recent years had their eyes opened to the future use of iron in fortification, and this only agrees with what has occurred under similar circumstances since the world began.

Men have always dimly foreseen every invention, every improvement, whether moral or material, long before the time has come for actually bringing it into practice. We must not stop here to enlarge upon this sentiment, except only as regards our subject. If, before any discovery or invention can be brought into use a number of dependent collateral circumstances must be brought into subjection to it—if, in fact, events must lead up to it—surely the time has come when the extensive use of iron in fortification is to be brought about, for recent events have led up to it in a very remarkable way: not alone have we improved and advanced so much in the general uses of iron, but lately we have been forced, almost as it were against our will, to do that in naval architecture which is here advocated in the architecture of fortification, and our enquiries as to the best method of carrying out this have so removed most of the difficulties and uncertainties, which originally beset the question as affecting fortification, that there really seems to be nothing in the way of our setting at once to work to put armour on our defences as the Admiralty are doing with their ships of war.

It is to be hoped that not only shall we turn our experience to good practical account in some of the new defences of the United Kingdom; but, also, that Military Engineers will, for all future time, look upon iron as a material which they may reasonably call in to their aid, and upon which they can alone rely, wherever complete resistance may be aimed at.

We are told that malleable iron has been known from very early ages; and, yet, it is somewhat remarkable, that, in this nineteenth century after Christ, we should still be engaged in important changes in the mechanical operations of its manufacture, and should be, as many think, approaching a great revolution in the method of producing this valuable material; and yet this certainly seems to be the case. Within the last few years great progress has been made in the treatment of iron after its elimination from the ore, and several very important processes, connected with its purification, have been patented; and although none are as yet completely successful, yet many embrace important principles, and almost all may be regarded as steps towards a great change.

The main object of all these inventions, apart from the production of large masses of metal of even quality, is of course the reduction of the cost of manufacture; but as this can be effected without any invention at all, by simply sacrificing quality, it follows that there would be a constant tendency on the part of the manufacturer to produce a cheap, though inferior material, were he not put under certain restrictions.

With the increasing importance of, and consequent demand for good iron, it becomes a matter of the first moment to see that the general quality of the iron of this country is not degenerating.

Much has been said and written upon this point of late, and although great good will no doubt result from public attention being drawn to the matter, yet it does not seem that any real cause for uneasiness exists, at any rate so far as our Government works are concerned.

It cannot be denied that the great discovery of smelting by means of pit coal, and, subsequent to that, the equally important improvement in iron smelting, namely that of working with hot instead of cold blast, have contributed, in no small degree, to lower the quality of the iron made in this country, by placing it in the power of the manufacturers, whose main efforts are continually directed to increase their produce, to employ such inferior materials in the production of cast-iron, as in former days it would have been impossible to employ profitably, or even to use at all; and so our markets have become stocked with every variety of inferior iron. Some people have gone so far as to say that good iron can neither be bought nor sold in this country now; but this, it is submitted, is not the real state of the case. There is bad iron in abundance now in use, both in public and in private works, but there is no reason why this state of things should continue.

There are many uses to which iron is put where nothing would be gained by an extreme refinement of quality; but wherever quality is to be first considered —as undoubtedly is the case where the iron is subject to artillery fire—we may be sure that Government can, by giving our great iron-masters full information as to what is wanted, and by a proper system of binding contracts, subject to the result of good practical tests of the material—amongst which should always be that of artillery fire, conducted by experienced people—obtain any quantity of iron of any given quality.

The trade may still produce inferior iron, but it will pass into those channels where quality is less considered than cost, and Government will command the attention of the iron trade to the production of the material best suited to the purposes of war, however difficult and unusual the manufacture may be.

But it must be admitted that some uncertainty still exists as to the best description of iron for resisting heavy blows from projectiles at high velocities, and until this be removed, it would seem impossible to furnish to the trade the precise data necessary for the adoption of the best system of manufacture.

A few words upon this point, before proceeding further with our subject, may be useful.

Recent experiments have shewn pretty conclusively that hardness is not the quality first to be sought in armour plates; "hardness" is only another name, as it were, for "brittleness" under sudden blows, and this tendency is quite inconsistent with endurance under artillery fire.

Of the great number of varieties of iron upon which experiments have been made, it would seem that good tough wrought iron stands the best, and we may define the iron which is most suitable for defensive works as that which bears the greatest ultimate elongation, under tensile strains, before fracture.

Cast-iron, steel, and all the varieties of steely iron, under the names of puddled steel, "homogeneous metal," malleable steel, &c., have been tried under all possible conditions, and have failed in comparison with soft wrought iron, at any rate when used in large masses.

It has been asserted by some chemists that the wrought iron which has best resisted heavy sudden blows has been that which was most free from phosphorus, and some, it is understood, go so far as to say that the mechanical resistance of iron to shot will be found to be very nearly in an inverse proportion to the quantity of phosphorus that it contains; but be that as it may, phosphorus no doubt is a highly dangerous element; it certainly has the effect of making a metal brittle when cold, commonly called "cold short," and that, as before stated, is the quality most to be avoided.

Sulphur is also a substance having a certain injurious effect upon wrought iron, it makes it "red-short," or the opposite of the effect produced by phosphorous, and although such an iron might be tough when cold, it would be difficult to work when hot, and hence the objection to it; but it is right to add, that this element rarely occurs to an extent sufficient to exert any appreciable effect upon the properties of metal, which has been submitted to proper purifying processes.

As these and many other substances, all exerting peculiar prejudicial effects upon the physical properties of the metal, according to the proportions in which they are found, and the combinations they may enter into, have to be removed from the pig iron in the puddling furnace, it does not appear surprising that the manufacture of any particular quality of iron should be so delicate a process, and that a very little care more or less bestowed should have a very marked effect upon the quality of the metal.

And when it is further remembered that the knowledge we possess of the actual influence of many of these substances upon the qualities of the metal is still far from perfect, and that even such definite information as we do possess on this subject has not received full attention in connection with physical experiments, it is not to be wondered at, that so many conflicting and apparently contradictory results should have been obtained in some of the experiments upon iron under artillery fire.

Passing, however, from this part of our subject, we will next consider what form this material of wrought iron should assume in order that it may have the greatest power of resistance.

Two methods of dealing with a question of this sort at once present themselves :—

The one, by theoretic discussion of the resistance of iron to impact of shot.

The other, by observations of the effects actually produced in the course of experiments.

For many reasons the latter course appears the most desirable.

Having given the amount of work accumulated in any moving shot, it may appear easy enough to measure the expenditure of work in punching or breaking or otherwise rupturing a given mass of iron with which it may come in contact, and so to account for all the accumulated work stored up in the shot; but it should be remembered that all our calculations of resistance to dynamic force must be based upon the effects produced by observed statical pressures, or, at the most, upon the results of bodies moving at velocities utterly insignificant when compared with those of common shot, and hence it is extremely doubtful whether any reliable results can be obtained from mere calculations.

The very suddenness of the shock introduces an extremely perplexing element into the problem, and when to this is added the injury to the shot itself and its consequent change of form during each instant of its action, and the innumerable conditions of strength or weakness dependent upon certain matters of mere construction, it must be admitted that however interesting and improving such researches may be of themselves, they cannot solve the great practical question we are considering.

It must be said in justice to this opinion that a very careful and elaborate series of experiments has been made by Government on the resistance of iron plates to statical crushing and punching pressures, and that a general formula for the penetration of wrought iron by shot has been laid down; but such was the uncertainty as to the amount of work lost by the breaking up of the shot that a constant derived from actual experiment had to be introduced into the formula, and even then the formula would apply only to cases similar to that of punching, and not at all to those where irregular fracture took place, thus bearing out very much what has been already said as to the value of mere calculations of the effects likely to be produced by shot at high velocities.

It would appear, then, that the other method, namely that of actual experiment, is, in the present state of our knowledge, the most satisfactory, and it need scarcely be said that it is upon this that our Government has most relied.

We will therefore now proceed with a brief account of the principal experiments that have been made upon iron in this country with reference to war purposes.

General Ford's Iron-Cased Wall, 1827.

The first recorded experiment that we have as yet found, is one that took place at Woolwich, in 1827, when Major-General Ford, R.E., proposed to ascertain the resistance to cannon shot of a piece of masonry covered with iron. This iron-cased wall, 5 feet high and 7 feet thick, was built of Aberdeen granite blocks, cased with two layers of iron bars, the under layer being horizontal, of 1¼ inch square, and the other vertical, of 1½ inch square bars; each layer being strongly cramped into the granite. This wall was fired at with round shot from three 24-pounders, at 634 yards' distance, when the effect of twenty round shot was that nineteen bars of the front layer, and five of the inner layer, were broken, four being entirely broken off, and the stone under them completely pulverized.

Thin Iron Plates at Woolwich, 1846.

After this, we find no records until 1846, when an experiment was carried on at Woolwich, under the direction of Colonel Colquhoun, R.A., and Major General Sandham, R.E., upon thin wrought iron plates, placed obliquely to the line of fire, at angles varying from 10° to 30°. The plates were ⅝ths of an inch thick, and placed in the first instance against a ship gun carriage, loaded with pig iron; afterwards attached to granite, and lastly to a mass of oak. They were fired at by an 8-inch iron gun, throwing a 56-pounder hollow shot, and afterwards by a 32-pounder of 56 cwt., at 100 yards. The principal thing to observe in this experiment is that the shot were almost always broken on striking the plate, and a quantity of splinters deflected, and that a 32-pounder shot striking at an angle of 30° where a former shot had struck, passed through the plate and all the 4 feet of oak. Another 32-pounder shot, fired with a higher charge, broke up, and some pieces penetrated 3 feet into the oak backing; otherwise, not much is to be learnt from this experiment.

"Simoom" at Portsmouth, 1850.

Then in 1850, the Navy made an experiment at Portsmouth, to try the effect of shot on ⅝th-inch plates of iron placed 35 feet apart (to represent the two sides of a ship), with ribs representing a section of the "Simoom." This was fired at with 32-pounders and 8-inch hollow and solid shot, and 10-inch hollow shot, and of course offered little resistance. Both shot and shell split and broke up into innumerable splinters, which caused great havoc. This experiment was continued with 32-pounders, 68-pounders, 8-inch and 10-inch hollow shot, the same year; the ⅝th-inch iron being backed between the ribs with oak and fir planking of different thicknesses, with ribs on the inside similar to the "Simoom"; the iron, wood, ribs, and all, were of course easily torn away, and the effect of splinters of both shot and iron was very destructive.

Four and a half-inch Plates, Portsmouth, 1854.

This was followed by experiments, also by the Navy, at Portsmouth, in 1854. Here there was a target composed of 4½-inch best scrap wrought iron plates, backed with 4 inches of fir planking, the whole bolted by heavy iron screw bolts to a strong timber framework, well braced and strutted. Ten 32-pounder shot from a 58 cwt. gun, charge 10 lbs., at 360 yards, struck the plates; a single shot indented 2 inches; two in nearly the same spot indented 2¼ inches, and slightly cracked a plate; four shot cracked a plate in four places, and bulged it 3½ inches; all the shot broke up. Two 68-pounder shot, charge 16 lbs., at 1,250 yards, indented about 1½ inches, cracked the plate, and were supposed to break up. Ten shot from the same gun, charge 13 lbs., at 400 yards, struck the plates, indentation caused by one shot, 2½ inches; each shot more or less cracked the plates, and several near the same spot injured them very much. Subsequently, 68-pounder shot, charge 16 lbs., at 400 yards, nearly destroyed the target and backing.

Thin Plates, 1854.

About the same time plates of ¼, ⅜, and ½ inch thicknesses, were fired at, and it was found that solid and hollow shot would pass through ¼ and ⅜-inch iron, without breaking; that hollow shot break up in passing through ½-inch iron, and that both solid and hollow break up in passing through ⅝th iron.

General Totten, United States Army, 1853 to 1855.

It is well known that from 1853 to 1855 General Totten, of the United States army, carried on some interesting experiments in some degree involving the question of iron defences. These are very fully described in Volume VIII of these Papers, but we will here briefly sum them up. In his first target, containing six embrasures, a variety of materials were tried—namely, granite, hydraulic cement concrete, asphaltic concrete, lead concrete, and brickwork. In one of these embrasures the throat was composed of wrought iron, 8 inches thick, made up of sixteen ½-inch thicknesses, set partly in cement concrete and partly in brickwork. In one, concrete of lead and cement was notched, and protected by wrought iron plates, 2 inches thick and 6 inches wide. And in one, these two plans were combined with asphaltic cement. His second target contained three embrasures. One had its throat or jambs composed of wrought iron, 4 inches thick, 10 inches wide, made up of eight thicknesses of boiler plates riveted together (rivets countersunk and flush), backed by a small mass of tough cast iron. This embrasure was built of granite, and had shutters in two leaves of three thicknesses of half-inch boiler plate. It is believed that there was thin sheet lead between the wrought and cast iron. Another embrasure in the second target was of similar construction to the last, only in brickwork instead of granite; there were no shutters, but a projecting portion of brickwork was protected by ½-inch wrought iron plate. The last embrasure was of similar form to the other two, but of cement concrete; it had the 8-inch wrought iron throat used in the former target, and a projection covered by ½-inch plate.

The general result of the experiments was, so far as iron is concerned, that grape shot passed through, or entirely carried away ½-inch boiler plate, but that canister shot produced no injurious effects; that shutters, 1½ inch thick, of boiler plate, stopped grape shot, but were bent by it, and were quite disabled by heavier shot; that the 2-inch offset plates of wrought iron did not stand against a 42-pounder at a range of 200 yards; that throat plates of 4 inches wrought iron, in ½-inch thicknesses, backed by cast iron, being struck two or three times by a 68-pounder solid shot, were carried away, the cast iron backing being cracked and broken; and that 8-inch wrought gorge plates, in sixteen thicknesses, were bent and finally torn from their fastenings by 42 lbs. solid shot at 200 yards, and even were considerably injured when struck several times by a 24-pounder, at 95 yards. The great advantage of a single mass of wrought iron over one composed of several thinner plates was noticed; also, that the brittleness of cast iron unfits it for use as a means of directly resisting heavy shot; and that a cast iron block, protected by a 4-inch compound plate, was always broken up, splintered, and badly cracked. It is almost unnecessary here to notice the performance of the other materials; but it is interesting to remember that next to wrought iron, lead concrete proved the best material. It is of course less resisting and more costly than wrought iron, but it will not crack and splinter. Heavy shot at high velocities moulded for themselves a symmetrical bed in which they were found crushed; in fact, the effect was quite local, and even shells exploding in it produced no cracks.

Sir John Burgoyne's proposal, 1856.

In the middle of 1856 Sir John Burgoyne collected what little had been done in the matter of applying iron to parapets of batteries, both floating and on shore, and moved the Government to consider the important question of giving better cover to guns, and by the use of iron to reduce the external openings of embrasures. Several high authorities were consulted, and some good opinions given. From what had then been done, it appeared that 4½-inch wrought iron on a ship's side was penetrated to a depth of 2¾ inches, by a 68-lb. shot, at 400 yards; that 4½-inch wrought iron plates completely protected a ship's side against 68-pounders at 1,200 yards; that they gave considerable protection against the same gun at 600 yards, and but little at 400 yards; that they gave considerable protection against 32-pounders solid, and 8-inch 56 lbs. hollow shot, at 400 yards; a 32-pounder shot penetrated only 1½ or 1¾ inches, and the hollow shot only 1 inch; but that three or four shot of the same kind striking near together did break up the 4½ inch plates.

3·94-inch Plates, France.

From some experiments in France, iron plates, 3·94 inches in thickness, were found to resist about fourteen shots per square metre (10¾ square feet, English) from a French 30-pounder (English, 32·4 lbs.), at 300 metres distance; and 5½-inch plates gave a resistance of eighteen shots per square metre.

Large Cast Iron Blocks, Woolwich, 1857.

Many suggestions were made about this time and amongst them, that cast iron blocks should be tried; and in consequence, in 1857, experiments were carried on at Woolwich against large 8-ton cast iron blocks, 8 feet by 2 feet, 2½ feet thick, tongued and grooved together, and partially backed by heavy blocks of granite. They were first fired at from a 68-pounder, 95 cwt. gun, at 400 yards, charge 16 lbs., using solid cast iron shot; these shot made indentations of from 1·3 inches to 1·6 inches, and cracked, displaced, and broke up the blocks very much. Some wrought iron shot from the same gun indented from 1·6 inches to 1·9 inches, and broke off large fragments and scattered the iron in pieces of from 10 lbs. to 80 lbs. Subsequently a cast iron block, 6 feet × 4 feet and 2 feet thick, weighing 9 tons 13 cwt., was fired at from the same gun, at the same range, with wrought and cast iron shot, by which it was cracked all through. Cast iron shot broke up; wrought iron shot recoiled considerably, and were much flattened.

4-inch Plates, Woolwich, 1856.

After this, in 1856, wrought iron plates, furnished by different makers, 4 inches thick, backed by 2 feet of woodwork, were fired at by 68-pounders, at Woolwich. The cast iron shot, at 600 yards, indented from 1 inch to 2·3 and 3 inches, and cracked and bent the plates; wrought iron shot, at 600 yards, indented from 2·2 to 2·8 inches, and carried away pieces; cast iron shot, at 400 yards, indented 2·2 inches, and cracked the plates, drove in some bolts, and shattered the bulkhead; wrought iron shot, at 400 yards, indented 3 inches, and went right through a plate without cracking it. This large bulkhead, weighing more than 30 tons, was driven back, by the blows it received, 3 or 4 feet.

4-inch Plates and 2-inch Steel, 1857.

In 1857, more wrought iron plates made by different makers, 4 inches thick, and a steel plate 2 inches thick, secured by bolts to 2 feet of oak, were fired at from 68-pounders, at 600 and 400 yards, at Woolwich; the general result of which was that wrought iron shot at 600 yards passed through, and cast iron shot at 600 yards were resisted, but they crushed the iron, and by a repetition of blows would have ultimately destroyed the plates. At 400 yards the plates were quite broken up by both cast and wrought shot. Mr. Begbie's 2-inch steel offered no effectual resistance.

68-pounders and 32-pounders compared, Portsmouth, 1858.

In 1858, the effect of 68-pounders and 32-pounders, at 100 yards, against iron plates, was compared at Portsmouth, when one 68 lb. shot was found to do as much damage to a plate and more to the woodwork frame of a ship than five 32-pounders striking close together; at 20 yards some 4-inch wrought plates on a ship's side were not penetrated by a 68-pounder cast shot with full service charge; but a wrought shot, of 72 lbs. from the same gun, did just penetrate them. Also, it was found that hollow shot, red hot shot, and shell, made little impression on 4-inch plates at either 200 or 400 yards; though at 200 yards, the effects were much increased. At 100 yards two or three hollow shot, red hot shot, and shell, striking at the same spot, penetrated a 4-inch plate; and a single 32-pounder cast shot at that range sank deep into a 4-inch plate, but did not get through. At 20 yards, cast shot did very little more damage than at 100 yards. It was also important to observe that if a shot did get through iron, it did far more damage than if it had only gone through timber.

4-inch Armour on ship's side; Whitworth gun, Portsmouth, 1858.

In the autumn of 1858, a Whitworth 68-pounder fired solid cast and wrought shot against 4-inch wrought plates on a ship's side at Portsmouth, at ranges of from 350 to 450 yards. A cast shot at 350 yards dented a plate $\frac{5}{8}$th inch, bulged it $1\frac{3}{8}$th inch, cracked it and started 12 bolts, and at 400 yards much the same. A wrought shot at 450 yards went right through a 4-inch plate and 7-inch oak in the ship's side. After this the gun burst.

Floating Batteries, Portsmouth, 1858.

In November, 1858, the Erebus and Meteor, floating batteries, were fired at at Portsmouth. The former ship's side had a $\frac{5}{8}$-inch inside skin on iron ribs, outside this 5 or 6-inch oak plank and 4-inch wrought plates outside all. The Meteor's side was made up of an inner planking of oak from 4 to 9 inches thick, then 10-inch oak timbers 4 inches apart, then 6-inch outside oak planking with wrought 4-inch plates outside all. 32 and 68-pdrs. at 400 yards did no serious damage in-board to the Meteor, but 68-pounders penetrated the Erebus, and did as much damage as a volley of grape shot. The Meteor also resisted a wrought 68-lb. shot at 400 yards, and sustained only trifling injury in-board at 300 yards. A 68-pounder shell, with weight of sand = to bursting charge, indented a plate $\frac{7}{8}$th inch, but did not crack it.

Large 8-inch Plate, Woolwich, 1858.

In 1858, a large wrought iron plate, 6 ft. × 6 ft., and 8 inches thick, weighing 5 tons, leaning back about 10°, and supported by large fragments of cast-iron, used in some former experiments, these again backed with heavy blocks of granite, was fired at with 68-lb. solid, cast, and wrought shot, at Woolwich, at 600 and 400 yards, charge 16 lbs. At 600 yards a cast shot indented 1·25 inches, cracked the plate slightly on its face, and bulged it in with a wide crack behind, which was afterwards increased. At 400 yards a cast shot indented 1·4 inches, and extended the cracks very much. At 600 yards a wrought shot broke off large fragments, and in fact quite broke it up. The report adds that when this plate began to break up its destruction was as rapid as that of the cast blocks in 1857.

14-inch Thorneycroft Shield, Portsmouth, 1859.

In 1859, Messrs. Thorneycroft, of Wolverhampton, were consulted by Captain Hon. G. Wrottesley, R.E., about the use of rolled iron tongued and grooved bars in horizontal layers, as an inexpensive method of applying iron to resist heavy shot. The great advantage offered was that of producing a mass of wrought iron at about £15 per ton, whereas in other forms it had not been previously put together under thrice that cost. Sir John Burgoyne strongly advocated the principle, and a shield measuring 10 ft. × 4 ft. 6 in. high and 14 inches thick, with an embrasure opening in it, was tried at Portsmouth. On the first day's trial seven 68-pounder shot at 400 yards range, striking fairly, made a very trifling impression, except in those parts where large vertical bolts, passing through the heart of the bars, had weakened them. This iron mantelet shewed such powers of resistance on this occasion, that subsequently it underwent further trial with a 68-pounder at 400 yards; 6 cast-iron shot struck the target, were of course broken up, but indented 1 inch and cracked it slightly; one of these shot on an old shot mark, carried away a piece of the target. 8 wrought iron shot struck it, 1 chipped off a piece, 2 carried away parts of the top sill of port, 5 indented and cracked slightly. Greatest depth of indent 2 inches. Altogether, except for an error in construction, the result was considered very favourable to rolled iron bars in layers, and further trials hereafter described were soon determined upon.

Special Committee on Plates and Guns, 1859.

During 1859, a special committee carried on a series of experiments on iron plates of various thicknesses of which the following is an outline.

1½-inch, 2-inch, 2½-inch, 3-inch, Plates, Shoebury.

They commenced upon plates respectively 1½, 2, 2½, 3 inches in thickness, bolted to a timber target representing the side of a 50-gun frigate of oak, from 18 inches to 24 inches thick. A shell weighing 78 lbs. when filled with sand, charge 10 lbs., thickened at the head, fired from Sir William Armstrong's guns at 400 yards, passed readily through the 1½ and 2-inch plates, and of 4 shells fired against 3-inch plates, 2 were resisted, although they injured the plate and timber a good deal, and 2 passed through the plates, but not through the timber. An 8-inch shell (68-pounder) 16 lbs. charge, made a circular crack in a 2½-inch plate, but did not drive any of the plate into the timber. All these shells were of course broken. Puddled steel and cast-iron solid shot from Sir W. Armstrong's 80-pounder (11 lbs. charge) passed through the 2½ and 3-inch plates and timber, the steel entire, the cast-iron in fragments, doing much damage by splinters.

Trusty, 1859.

The "Trusty" was next fired at; her side consisted of wrought 4-inch plates on 2 feet 1 inch solid oak. At 400 yards, a 72-lb. cast-iron flat headed shot from Sir W. Armstrong's 80-pounder gun, broke the plates but did not pierce them; the shot broke up of course. The puddled steel shot broke in a large portion of a plate. A homogeneous iron shot fairly penetrated both plate and timber. At 200 yards the cast-iron conical headed shot, weighing 100 lbs., did a good deal of injury but did not penetrate. A homogeneous iron 78-lb. shot punched a hole through a plate and penetrated 10 inches into the timber; and a homogeneous iron shot of 100 lbs., at a lower velocity, did not punch a hole, but made a large fracture; oblique shots at an angle of 50° to the side of the vessel, caused less injury than direct shots. The bolts holding the Trusty's plates rarely yielded except when directly hit.

4½-inch Plates.

After this the same committee fired at some 4½-inch rolled plates from Messrs. Palmer's, and some 2-inch plates from the Mersey Company, bolted to a section of a 50-gun frigate, with homogeneous iron bolts, double nutted. The 2-inch plates could not resist Sir W. Armstrong's 80-pounder shell at 400 yards; the shell broke up, but always passed through the plate. A 68-pounder shell at the same range, 16 lbs. charge, broke the 2-inch plate, but did not penetrate deep into the timber. The 4½-inch plates had a hole punched in them by a homogeneous flat headed shot, and the plate was forced 3 inches into the timber, and several shot striking together, some of the plate was driven in 20 inches. Altogether these 4½-inch plates were considered to stand well.

4½-inch Armour, Portsmouth.

Some experiments were also about the same time carried on at Portsmouth, tending to shew that three 68-lb. shot, striking close to the same point, will, at 200 yards, break up and drive in 4½-inch wrought iron plates attached to a timber ship's side. This committee came to the conclusion that although thin wrought plates will break up cast-iron shell, little advantage will be gained by the use of iron, unless it be strong enough to resist both the fragments of shell and of cast-iron shot; that ships with 4½ inches of rolled plates were invulnerable by any projectile then in use, and that plates should be strongly backed and secured by strong wrought iron bolts with double nuts.

Jones's Butt, Portsmouth, 1860.

In August, 1860, Jones's (miscalled) angular butt was tried at Portsmouth. It consisted of a series of ribs of ½-inch iron plates, 21 inches deep, spaced 14 inches apart, connected together at the outside, and at the top and bottom with ½-inch iron pieces, screwed and nutted to the ribs; outside this was laid 13½ inches of stout fir planking, and outside this again the armour plates; the whole structure measuring 39 inches through, and being placed at an angle of 52° with the vertical plane. The armour plates were 4½-inch and 3½-inch steel, and 4½-inch wrought iron from the Mersey works, and 4½-inch of Derbyshire iron. The butt, with a strong and solid foundation, and well supported by stanchions, was placed on the upper deck of an old vessel and fired at with a 68-pounder solid cast-iron shot, 16 lbs. charge; range 200 yards. The result of 35 rounds was reported to be that the penetration was less than half that on perpendicular plates, and that the effect on the woodwork backing was very slight, compared with that when the plates are on a ship's side. The Derbyshire wrought iron was extremely brittle; that by the Mersey Company was far better; the steel plates useless. One 4½-inch Mersey wrought iron plate, 7 feet × 3 feet, took 17 blows in an area of 13 square feet before any part of it was removed, and then, even, the iron was not penetrated nor the woodwork much injured.

Comparison of Elongated and Spherical Projectiles, 1860.

A general comparison was also made about this time between the effects of elongated and spherical shot upon iron plates at 200 yards, which went to show that an elongated shot penetrated more than a spherical one, striking with the same momentum, but the blow of the elongated was less spread and the smashing effect less. Also, that a flat headed elongated shot penetrated deeper than a spherical, because the latter spreads out on striking, and thus has a larger surface opposed, while the elongated shot punches a hole out for itself.

Thorneycroft 10-inch Shield, Shoebury, 1860.

In the autumn of 1860, a further trial was made at Shoeburyness, of the Thorneycroft principle on a shield 12 feet × 5 feet 4 inches, with an embrasure opening of 23 inches × 39 inches, composed of rolled bars 10 inches wide and 4½ inches thick, with tongues and grooves. There were thus 6 long bars and 16 short bars; the shield was applied to the front of a masonry casemate, and a 68-pounder gun was mounted in the casemate on a traversing platform. It will thus be seen that this shield was but 10 inches thick, or 4 inches less than that tried at Portsmouth, and before described. The principal points in which it differed from the Portsmouth shield was that instead of the several bars being held down by bolts passing through them, they were in this case clamped together by 3-inch vertical tie bolts at their back at each end, and these passed through bonding irons at the top and bottom; the whole was well bedded in the masonry, and tied through the whole thickness of the parapet by strong iron rods; the shield was moreover backed by masonry over its whole surface. This shield was first fired at with grape and segment Armstrong shells, at 400 and 600 yards, from 68-pounder, 32-pounder, and 25-pounder Armstrong guns, and from the diminished size of the embrasure, the effect upon the inside of the casemate was favourable. After this a number of rounds (about 21) with wrought and cast shot, were fired from 68-pounder, and 80 and 40-pounder Armstrong guns, at 600 yards, and without any serious injury.

				in.		in.
The	68-pounder	indented	about	1⅛	to	1½
,,	80-pounder	,,	,,	1		
,,	40-pounder	,,	,,	¾		
,,	grape	,,	,,	¼		

The masonry of the parapet was struck several times and fearfully injured.

10-inch Thorneycroft Shield without backing, Shoebury, 1860.

After this another experiment was made upon the same shield without masonry backing, the masonry only giving it support at its two ends.

In this trial it received 29 blows from 68-pounders, and 80-pounders, and 40-pounders, at 600 yards, with wrought and cast iron shot, and stood very nearly as well as with the stone backing. It will thus be seen that the shield received 50 shots in all. One bar had a piece knocked out of it; one or two slid laterally a few inches; a few had cracks in them : but altogether the shield was but little injured. No indentation exceeded 1½ inch.

Effect of Sound.

A short time after this an opinion gained ground that the effect of the sound arising from the discharge of heavy guns, out of an iron embrasure of this construction, would be an obstacle to its use, and to test this a number of shots were fired from a 68-pounder, at every possible degree of lateral range and elevation, and no inconvenience whatever was felt by any person in the casemate.

Iron Embrasure Flaring Cheeks, Shoebury, 1860.

Together with the trial of this 10-inch Thorneycroft embrasure, a trial of another wrought iron embrasure of special construction was made.

This consisted of four massive pieces—namely, two cheeks or side pieces about 8 inches thick, set splayed to allow a lateral traverse of 60°, with a sill and head piece 4 inches thick; the whole was very firmly bolted and dovetailed together, and proved very strong; but the defect of the flaring cheeks was so apparent, in comparison with the small opening of the Thorneycroft embrasure, and the effect of the splinters and grape led in by these sloping cheeks so destructive upon the interior of the casemate, that the principle, although possessing some advantage as to strength, was soon given up.

It is right, perhaps, that it should be here mentioned that on a subsequent occasion the 10-inch Thorneycroft shield, above described as about proof against an 80 lb. shot, was found to be unequal to a blow from a 120 lb. shot, thrown from Sir W. Armstrong's shunt muzzle loading gun, and that a 156 lb. shot from the new 12 ton gun, at 200 yards, completely broke it up.

Special Iron Committee, 1861.

Early in 1861 the special committee on iron was appointed, and during the whole of the past year they have been fully occupied with a vast number of very important investigations, directly bearing upon our present subject. It is to be regretted that, as the proceedings of this Committee have not been made public, we are greatly restricted in the use we should otherwise have wished to make of their experiments in this paper; as it is, we shall confine ourselves to a brief notice of those matters with which we have become acquainted by personal observation, and that will not be more than lies in the power of the great number of officers and civilians who have attended the experiments at Shoeburyness.

It should first be mentioned that perhaps the more important, immediate, and difficult object of inquiry of this committee, has been that of giving the most effective armour to our navy; but the question of iron, as used for defence generally, has also occupied much of their attention, and the greater part of their experiments is as useful and instructive to the designer of fortifications as to the naval architect.

But before proceeding to examine the results of their experiments generally, we will dispose of the trials of Thorneycroft's principle, subsequent to the experiments just described, as that will complete this subject, so far as it has at present gone.

The 10-inch Thorneycroft shield, fired at by the Ordnance Select Committee, having given great promise of success, and the principle appearing to give greater strength for the same money than by any other plan, it was determined to prosecute the enquiry further, and to erect two new shields. It must be admitted that a false step was taken in fixing the thickness of these two shields. When the original Portsmouth 14-inch shield had been tried, and except for a certain defect in construction, found very good, instead of cautiously taking off little by little, so as to find a safe minimum, 4 inches in thickness, or 28 per cent. was taken off at one step, just at the time when projectiles were getting larger and flying faster, and the 10-inch shield was tried at Shoebury. This proved, as above stated, equal to a certain gun, but quite unequal to resist the heavier projectiles coming into the service.

10-in. and 8-in. Thorneycroft, Shoebury, 1860.

Instead, therefore, of putting on some strength, so as to make up 12 inches in thickness, another 10-inch shield of much larger dimensions, and under considerably less advantageous circumstances, and of very questionable and ill-contrived construction, was brought out; and to make matters worse, another shield of only 8 inches thickness was ordered. The trial of these two against such blows as the 100-pounder service and 120-lb. shunt gun can give, at 400 yards, led to what might have been easily foreseen, and the two targets completely broke down. We will roughly describe them and there the matter shall drop for the present at any rate. The 10-inch shield was made on the independent principle—that is to say, it was to be self-supporting, without any aid from the rest of the fort, or other work of which it might form an embrasure. It presented a front of 12 feet × 8 feet, with an opening or port for the gun. It consisted of bars in section 10 in. × 4½ in., tongued and grooved as before, but 5 of the bars viz., 1st, 8th, 12th, 19th, and 21st, had dovetails on the whole length of their back, on which upright backing pieces fitted, which were intended to bind the mass from top to bottom; the shield was supported at the back by massive rolled iron struts footed down into sill pieces of the same material. The 8-inch shield was composed of bars 8 inches × 3¾ inches, with similar backing pieces, but supported at either end by masonry piers to which it was bolted. On the first day's firing at the 10-in. shield the backing pieces gave way at the dovetails, and the mass not being tied together, the bars got displaced and broken, and ultimately the whole shield being driven off its solid bed, it fell over and buried its face in the sand. On the second day strong vertical iron shackles had been prepared in order, as a temporary measure, to supply the place of the backing pieces that had failed; these made the shield offer considerably greater resistance, but when they ultimately gave way the shield could not stand against the 120 or 100-pdr. guns. The 8-inch shield could not even stand two 68-pdr. shot, striking near the same spot, and a 100-pdr. destroyed the target; shackles, as before, were afterwards added, but although they had some effect, the shield was quite unequal to the gun brought against it.

The reason that so much space is here devoted to this subject of the Thorneycroft bars, is that on account of the extreme simplicity of the principle and its cheapness, the bars being all of one section, simply rolled without any machine work upon them, and consequently in the cheapest form in which wrought iron can be well produced, it promised for some time to surpass any other method of applying armour to fortifications; and, although it is hoped that a more advantageous plan has now presented itself for land defences, it is not clear that with certain improvements in detail of construction and manufacture, the principle may not be adopted, at any rate, as an auxiliary to other principles. However, it is feared that too much has been already said about them, and we will therefore pass on to a slight review of what has been done in 1861.

At the commencement of their proceedings, the Iron Committee, besides consulting all practical and scientific men of experience in the manufacture of iron in this and in other countries, invited all the principal manufacturers to send in plates for experiment. The plates were tried at Shoebury, fixed vertically without backing against strong timber frames.

Plates of homogeneous iron, of hammered and rolled iron of various qualities and make, steel, and steel and iron combined, and even copper, have been tried. We are not aware that any other metals have been fired at. Sets of plates of all thicknesses from ¼-inch up to 3 inches, made by more than twelve different firms, underwent trial and test of every possible description, from the very rough and ready and most unerring one of artillery practice, to the delicate and less conclusive test of chemical analysis; and all the laborious mechanical test and examination as to specific gravity, tensile strength, resistance to compression, punching, shearing, torsion, &c.

A breach-loading wall piece, throwing a 5½-oz. ball, with initial velocity of about 1,100 feet, was used upon plates up to 1 inch thick, at a range of 25 yds.; roughly speaking, a steel, lead coated, cylindrical flat headed bullet punched a clean hole through the ½-inch rolled, hammered, or homogenous plates, but did not always get through ¾-inch plates, and stuck in an inch plate, making a hole about ¼ inch deep.

A 6-pounder Armstrong gun, throwing solid cylindrical cast-iron shot, with hemispherical head at 1,125 feet initial velocity, range 50 yards, did not get through 1½-inch plates; a 12-pounder Armstrong, throwing cast-iron shot, initial velocity 1,150 feet, at 100 yards, did not get through 2-inch plates; and a 25-pounder Armstrong cast-iron shot, at 100 yards, did not get through 2½-inch plates; a 40-pounder Armstrong, at 100, did not get through a 3-inch plate.

The wall piece, at 25 yards, throwing a cylindrical flat-headed tempered steel projectile, got through 1-inch copper.

The 6-pounder Armstrong did not get through 3-inch copper, but the 12-pounder Armstrong did.

Armour on Brickwork, Shoebury, 1861.

In May, 1861, a very interesting experiment was instituted to ascertain what protection would be afforded to brickwork by iron plates of 2-inch, 2½-inch, 3-inch, and 3½-inch thicknesses. The plates were of rolled iron 2 feet 6 inches wide, and 4 feet 6 inches and 5 feet 6 inches long. Each plate was secured by six 2-inch bolts, with countersunk heads; an existing wall about 8 feet thick was used for the trial, and its face was first taken down to a depth of 4 feet; at that depth rolled iron bars were placed vertically in the work (the common railway rail was used for cheapness and expedition), their lower ends being firmly driven down into the foundations, their upper ends held back by a horizontal bar, which was secured at intervals of about 2 feet by bolts to the rear of the work. The bolts were bolted to the vertical bars and secured by double nuts, and the brickwork built up solid in cement around them.

A 12-pounder cast-iron solid shot, at 600 yards, had no effect of course.

A 25-pounder cast-iron shot, at the same range, cracked the 2-inch plates, but did little damage to the others, and none to the masonry.

A 40-pounder cast iron shot, at the same range, penetrated all the plates, except the 3½-inch, but did little damage to the masonry behind.

A 68-lb. cast-iron shot, at 500 yards, penetrated the plates, but after 10 shots (the target, 10 feet square, having previously received 32 of the light shot), the plates were not displaced, but held firmly in their places by the bolts, which stood exceedingly well, and the wall was almost as complete for defensive purposes as before firing commenced.

After this a 100-pounder Armstrong gun, firing shell filled with sand, weighing 104 lbs., and a 68-pounder, throwing solid shot and 8-inch shell, were brought to bear at 400 yards.

The 100-pounder shell, with sand, penetrated all but the 3½-inch plates; and after about 14 rounds with these and 68-lb. shot, the plates were a good deal damaged, and then live shell were used. A live shell, 100-pounder, with 8½ lbs. of bursting charge, striking an iron plate, did little or no injury, but of course it did great damage when it entered the brickwork, where the plates had been broken away, and ultimately the plates and front of the wall would have been completely destroyed.

The result of this experiment may be set down in a few words, viz., that a brick wall covered by 3½ inches of iron in this manner would be quite proof against the battering guns at present in the service, but that if it has to resist guns about equal to our 100-pounders or 68-pounders, it should be covered with about 5 inches of armour, and that the mode of securing in this experiment was satisfactory.

Inclined Plates, Shoebury, 1861.

About this time the question of the relative increase of resistance given to iron plates, when inclined at various angles, was again brought up; and in apparent contradiction to the experiments at Portsmouth, on Jones's butt, in 1860, there was found to be no apparent difference in the powers of resistance of ¾-inch, 1½-inch, and 3-inch plates, whether they were placed at angles of 30°, 45°, 60°, or vertical. The plates were without backing, merely held on to a skeleton framework of wood. They were fired at by the wall piece, 6-pounder Armstrong, 12-pounder, and 40-pounder, at ranges of 25, 50, and 100 yards; the bullets of the wall piece were of steel, flat headed cylindrical, and the other shot of wrought and cast-iron.

Subsequently, in continuation of this experiment, two plates of wrought iron, placed respectively in a vertical position, and at an angle of 45°, were tried, each having a 12-inch oak backing, and there being in them an equal weight of iron for the same vertical height—

The inclined one was 3¼ inches thick.
The vertical .. .. 4½ inches thick.

They were fired at from a 40-pounder, at 100 yards, and there was scarcely any difference in the resistance offered; in each case a dent of about $\frac{8}{10}$-inch was caused.

Afterwards, a 100-pounder, at 200 yards, sent a hemispherical headed shot through the inclined plate, but it did not get through the vertical; a square-headed 100-lb. shot did not penetrate the inclined plate so much as the hemispherical-headed shot; altogether the vertical plate may be said to have stood best.

Whether the apparent discrepances between these results and those at Portsmouth, are to be accounted for by spherical shot having been used in one case and elongated in another, or whether they may not be reconciled in some other way, we are not prepared to say; but at any rate, the effects are worth considering, and the experiments should be carried further until the differences are accounted for.

6½-in. and 4½-in. Plates, Shoebury, 1861.

In July, 1861, two plates of 7 feet × 3 feet, of hammered scrap, unbacked, respectively 6½ and 4½ inches thick, standing vertical, were fired at, at 400 yards range. A cast-iron shot, 126 lbs., from Armstrong's muzzle-loading shunt gun, struck the 6½-inch plate, made an indent of 1·9 inch, and cracks were shewn behind, and another shot of the same nature struck the 4½-inch plate, and cracked and bulged it very much; another of them, and two

110 lbs. cast-iron shots, quite destroyed this 4½-inch plate; while the 6½-inch plate, after receiving three fair shots from the 126-pounder, was also broken up.

Roberts's Target, Shoebury, 1861.

During that summer, also, a target of special construction, provided by a Mr. Roberts, was tried.

This consisted of a mass of timber and T plates, protected by armour plates 3 and 4 inches thick, of malleable scrap iron, about 2 feet wide, hammered and rolled to such form as to present a series of angular projections, ridges and furrows; the apices of the angles were pointed with steel.

It was altogether of too complicated and costly a construction; and, although the armour plates were of very good iron, it was separated and opened out, and the fittings damaged, and ultimately all destroyed by a few 68-pounder and 100-pounder shot.

Mr. Fairbairn's 1st Target, Shoebury, 1861.

Another target, of a construction proposed by Mr. Fairbairn, was tried about this time.

It consisted of rolled plates 5 inches thick, attached by a number of 1⅜-inch screws to a ¾-inch sheathing, supported by wrought iron built up ribs of ½-inch plate, 12 inches deep and 18 inches apart, the screws were 7½ inches apart, and tapped for a depth of 2 inches only into the back of the plate. The plates themselves stood remarkably well, but the tap screws broke off so easily that the armour became completely separated from the rest of the target, and so became useless. Four inches of elm on the face of this target decreased the effect.

Captain Coles's Cupola, Sheerness, 1861.

The trial of Captain Cowper Coles's Revolving Cupola Shield, which was made by the Admiralty off Sheerness, in the autumn of 1861, must be next mentioned.

This shield was truncated-cone-formed, and gave cover to one gun; cupolas to cover two guns are now being designed.

Captain Coles's primary object is to adapt these shields to the navy, with a special construction of sloping decks; but it is believed that he also advocates their adoption for land defences, and it is on this account that they are noticed here.

The revolving cupola is composed of massive timber about 18 inches thick, covered with armour plates 4½ inches thick; the internal diameter of the cupola is about 12 feet, and the height about 8 feet inside; the sides are inclined to the horizon at an angle of 40°.

The gun is mounted on a special carriage, and its muzzle extends some feet outside the port; the chase of the gun just in front of the trunnions rests on the sill of the port.

The whole cupola revolves by means of winches on a sort of turntable, so that the training of the gun is effected by turning the whole apparatus; and the porthole, therefore, is only a narrow slot long enough to permit the gun to be elevated and depressed.

On the day of trial the cupola, as erected on the "Trusty," was subjected to very severe tests, not only to try its endurance under fire, but also to test the working of the machinery under all circumstances; and it was proved that even after heavy battering, and with the vessel heeled over several degrees, there was no difficulty or obstacle whatever in working the apparatus; on the contrary, it afforded very great facilities for rapid and accurate firing, and for keeping a moving object in sight, and this with a very small complement of men. A great number of shot (nearly 100) were fired from the 40-pounder Armstrong gun in it, and then it received a few shots from a 40-pounder, and a great many blows (26) from a 100-pounder at 200 yards.

Four 100-pounder shot striking very near the same spot broke through into the cupola, but the machinery worked as well as before.

The muzzle of a cast-iron gun, mounted in the cupola, was struck by a shot; the gun broke off a short distance in front of the trunnion, and a portion went overboard.

After this a 68-pounder was laid upon it, at 200 yards, and had much the same effect as the 100-pounder, but the cupola was never thrown out of gear; there was no difficulty from smoke, and only a little from concussion; and altogether its performance was considered highly satisfactory.

Various Backings to Iron Plates, at Shoebury.

After this, in order to test the various effects of different sorts of backing, some 2½-inch wrought iron plates were fastened respectively to blocks of cast-iron 3 feet thick, to solid granite, to a mass of oak made up of timbers 10 inches by 10 inches, and to a mass made of alternate layers of fir and cork, and bitumen and cork.

The results proved the superiority of a massive rigid backing over an elastic backing, as regards the plates themselves, but not as regards the fastenings.

A 40-pounder service shot, at 200 yards, did little or no damage to the plates backed by granite and cast-iron, but went clean through the plates backed by oak and fir, and did great damage to them.

A 100-pounder cracked a plate backed by cast-iron, and the cast-iron also, but did little damage.

While, on the other hand, none of the bolts securing the plates to the elastic backings were injured, but several securing them to the granite and cast-iron were broken off.

Warrior, Shoebury, 1861.

Later in the year, a target, representing a piece of the "Warrior's" side was fired at from 68-pounders, 100-pounders, and 120-pounders. The target was constructed exactly similar to a midship section of the "Warrior." The ribs of the ship were from 2 feet 1 inch to 2 feet 3 inches apart, and 10 inches deep, made up of ½-in. web and ∟ irons, 4 in. × 3 in. × ⅝ in. Outside these came the sheathing of ⅝-inch plates, and outside this again there were strengthening pieces of ⅝-in. plate covering the joints of the armour plates, and covering altogether about half the area of the side; then came 9¼ inches of teak timbers laid horizontally, and 7¾ inches laid vertically, protected by the large armour plates 4½ inches thick, tongued and grooved on their edges, and held on by 1½-inch bolts passing through all, in the proportion of one bolt to about 3¼ feet superficial of ship's side. It measured 20 feet by 10 feet, and had a port-hole in the centre, and was struck by 13 solid shot, besides six experimental 200-lb. shot, thrown with a reduced charge from a 100-pounder gun, and by 10 shells.

The result was that although the armour plates were more or less cracked and indented, and deflected especially where 12 shots (of which one was a steel 100-lb. shot) struck a plate within an area of 4½ square feet, the back of the target, agreeing with the ribs and sheathing of the ship, was not at all injured.

Mr. Hawkshaw's 6-inch & 10-inch Laminated Shields, Shoebury, 1861.

Two targets, proposed by Mr. Hawkshaw, were next tried; the one was 6 inches thick, composed of a number of thicknesses; the front layer was 1½ inch, and the rest made up of seven ⅝-inch boiler plates, held together by alternate rivets and screws, 8½ inches from centre to centre, all over the target; the rivets had countersunk heads in the front.

The other was 10 inches thick, made up of one 2-inch and thirteen ⅝-inch plates held together much as before. The weakness of a number of thin plates, as compared with a solid mass, was here very apparent; the 6-inch target was deeply dented by a 40-pounder, at 100 yards, and both 68-pounder and 100-pounder, at 200 yards, went clean through, breaking off many of the rivet heads.

The 10-inch target was bulged in very much by the 100-pdr. and 68-pdr., and several thicknesses of the ⅝-inch plates at the back were broken; the 68-pounder had rather more effect than the 100-pounder.

Shield of another construction, 1862.

Soon after this, a target measuring 11 ft. 8 in. by 8 ft. 2 in., on a principle proposed by myself, was tried at Shoeburyness. It represented a shield to close the front of a masonry casemate, but the principle admits of very general application.

It was composed of planks of wrought iron, first hammered and then rolled, 5 inches thick and 14 inches wide, crossing each other in alternate layers at right angles—in fact representing what is called in carpentry "planking and cross-planking."

One half of the shield had two layers of planks and was therefore 10 inches thick, the other half had three layers.

The several layers were secured by 2½-inch screw-bolts, and each nut had two washers, one of iron the other of lead.

It was intended to introduce sheet lead between the layers of planks, but this had to be abandoned at the last moment on account of a mistake made in the length of some of the bolts.

The shield was supported at either end by diagonal boiler plate struts, secured to a strong iron beam in the rear, built into masonry, by which means alone the shield is kept in its position, and it is therefore rendered as independent as possible of the adjoining masonry.

It was fired at from 40-pdrs., 68-pdrs., 110-pdrs., 120-pdrs. (shunt gun), and the 12-ton gun throwing a solid spherical shot of 156 lbs., with charge of 50 lbs., at a range of 100 yards.

The injury done to the shield was not great until struck by the shot from the 12-ton gun, and even then the effect was principally confined to the outer layer of planks.

Some of the bolts gave way and the planks were cracked through the bolt holes.

Altogether it may be said to have stood very fairly, and with certain modifications the principle may no doubt be turned to good account. It certainly has the advantage of extreme simplicity, capability of almost universal application, and facility of repair. Additional strength could also be given to a work of this construction, at any future time, without difficulty. And the principle bids fair to admit of a large share of strength being obtained at comparatively small cost.

The rapidity with which such a shield can be erected is also worthy of notice.

Subsequent to these experiments, targets representing ships' sides of various constructions have been tried at Shoeburyness.

Committee's Target.

The first of these was one designed by the Special Committee itself, and made by Mr. Fairbairn.

It was intended to determine by this target whether the 17 inches of wood in the "Warrior" is advantageous or otherwise. In this case the 4½-inch armour plates were fastened by means of 2-inch bolts to 1-inch plates forming the skin of the ship, and this skin was supported by ribs 18 inches deep and 18 inches apart, made of ⅞-inch plates and 4-inch angle irons—there were also strips of iron plate on the back of the ribs.

In weight, this target was a little more than the "Warrior."

The result of the first day's firing was very conclusive as to its weakness. As the same blows that had little or no effect upon the fastenings of the "Warrior" on former occasions, now broke off in numbers, the 2-inch bolts securing the armour plates of the target, so that by a very short time it would have become quite defenceless; and this notwithstanding that the proportion of sectional area of bolt to superficial area of armour plate exceeded that in the case of the "Warrior" in about the ratio of 15 to 11.

On a subsequent occasion, various substances such as felt dipped in tar, and vulcanized india-rubber, were inserted between the armour and the skin, and india-rubber washers were used, and some conical headed rivets were substituted for the bolts, but with all this, the inferiority of this target to the "Warrior" was very apparent.

Mr. Samuda's Target.

The next was a target designed and built by Mr. Samuda. It consisted of 5-inch armour plates, backed by 1-inch plates, and 2½-inch pieces covering the joints of the plates, and the whole supported by ribs 7 inches deep and 2 feet 2 inches apart.

It was quite apparent that this target also could not compete with the "Warrior," although a greater weight of material was used in it. It was very much injured by 68-pounders and 110-pounders, and the 156-lb. shot went clean through it.

Mr. Scott Russell's Target.

A very large target was next constructed to test a system of continuous riveting proposed by Mr. Scott Russell. The armour plates were 4½ inches thick, and 3 feet and 1 foot 9 inches wide, and were backed by 3 inches of iron in three thicknesses, which were supported by sheathing in two thicknesses of ⅜-inch boiler plate, and ribs 10½ inches deep and 1 foot 9 inches apart.

The continuous riveting was used as a method of holding on the armour plates, and bolts were therefore entirely dispensed with. The process may be thus described:—

The iron backing being fixed in its place on the sheathing, large T irons were secured to it by means of strong rivets, with countersunk heads passing through the upper table of the T iron—thus the remaining limb of the T projected from the side of the ship, and its length was something greater than the thickness of the armour plates.

These T irons were arranged at intervals corresponding with the widths and lengths of the armour plates, and the process of converting them into continuous rivets, as Mr. Russell calls them, was by heating the projecting part by means of a blast flame, and when red hot, hammering it down over the edges of the armour plates—thus in one case a rounded off projection was left over the joints of the plates, while in another case the riveting was made quite flush by means of a rounded hollow on the edges of the armour plates.

This target received similar treatment to that of the "Warrior" on the day of experiment, but, notwithstanding the great additional weight of metal used in its construction, it could not compete with that target.

The continuous riveting, especially that which was flush, certainly did very well on this occasion, and although more or less injured, it still performed the duty expected of it; but the whole structure did not withstand the battering it got from 110-pounders and 68-pounders so well as the "Warrior," and the 156-lb. spherical shot from the 12-ton gun, with 50-lb. charge, at 200 yards, made a breach completely through the ship's side; the fragments and splinters, however, were caught by an inner lining attached to the insides of the ribs.

The effect of vibration upon plates with iron backing was shewn in a very remarkable way on this target, where a 4½-inch plate was cracked through a bolt-hole situated more than 6 feet from the point of impact.

Further trial of the Warrior, 1862.

The "Warrior" having hitherto withstood with great success the severest trial that could be given it by 68-pounders, 110-pounders, and the 120-pounder shunt gun, it was determined to continue the experiment from the new 12-ton gun at 200 yards range. The first shot, spherical, 156-lb., struck close to the edge of a plate which had previously been struck by several shot and shell. It pierced the armour plate, cracking it in adjacent parts, shattered the teak backing, and bulged and cracked the inner sheathing of the ship and a rib, but did not pass through.

A second of the same shot, with the same charge and at the same range, struck within 12 inches of the same spot, and also on the edge of the same plate, and added immensely to the previous damage; besides enlarging the fracture in the armour plate, the teak was still further shattered, and the sheathing of the ship completely ripped open and very much damaged, one of the ribs also was forced inwards and broken in two, and two others broken; but neither in this case had the shot passed through.

After this, three separate 156-lb. spherical shot, fired with 50 lbs. of powder, at 200 yards range, struck fairly upon comparatively uninjured parts of the same target, and near the centres of the plates. In each case the armour was pierced with comparative ease, a circular hole being made of little greater diameter than that of the shot, the effect upon the plate being quite local, but, to the surprise of every one, little or no damage was done to the sheathing or ribs of the ship. It would appear that the 17 inches of teak performed a very important office in so dispersing the shattered fragments of the shot that the effect was distributed over a considerable area of the sheathing, and so all serious injury to the inner structure of the ship was avoided. In neither instance of these three shot would the slightest injury have occurred inboard the ship in action, nor would the men fighting the guns have been in the least degree inconvenienced.

It remains, however, to be seen what would be the effect of a wrought iron shot striking the same target with similar force. The general opinion is that it would go completely through, and do great injury inboard. It is highly necessary that this should be tried.*

* It may be here mentioned that a wrought iron shot, weighing 162 lbs., has lately been fired with 50-lb. charge from Sir W. Armstrong's 12-ton gun at Mr. Scott Russell's target, and that it opened a large hole through the whole structure, sending a number of splinters inboard, and injuring all adjacent parts to a very serious extent; singular enough in this case, the shot in the process of penetrating the target became so much flattened and enlarged in diameter that at last it could not pass through the hole it was piercing for itself, and ended by bounding back to a distance of 8 or 10 feet.

Several further experiments upon targets representing floating structures, are about to be tried; and a number of suggestions have been made affecting the construction of Land Works, many of which deserve trial. It being certain that liberal expenditure in experiment now, will lead to great saving of useless expenditure hereafter, the prosecution of a systematic and connected course of experiments, especially with reference to Land Defences, is strongly recommended—first determining certain general principles of construction, and then deciding step by step upon the innumerable matters of detail which are sure to arise.

Summary of Experiments.

The following summary of the effects produced on the various thicknesses of iron, in the course of these experiments, may be found useful:—

¼ and ⅜-inch.—Both hollow and solid shot pass through without breaking.

½-inch.—Hollow shot pass through, but are generally broken up. Grape pass through, but not canister.

⅝-inch.—Solid shot break up in passing through.

¾-inch.—Wall piece, throwing 5½ ozs. ball, with charge of 10 drams, at 25 yards, not always through.

1-inch.—Proof against same wall piece; indent ¼-inch.

1½-inch.—6-pounder Armstrong, at 50 yards, not through.

2-inch.—12-pounder Armstrong, at 100 yards, not through; indent 1 inch to 1½ inches.

2-inch (oak backing).—80-pounder shell, filled with sand, passed through at 400 yards.

2-inch (brick backing).—12-pounder Armstrong, at 600 yards, resisted.

Ditto.—25-pounder Armstrong, at 600 yards, just penetrated.

2½-inch.—25-pounder Armstrong, at 100 yards, not through.

2½-inch (oak backing).—8-inch shell, at 400 yards, not through.

Ditto.—80-pounder steel and cast-iron shot, through.

2½-inch (brick backing).—25-pounder Armstrong, at 600 yards, not through.

2½-inch (cast-iron backing).—12-pounder Armstrong, at 200 yds., indent ·5 in.

Ditto,	ditto,	40-pounder Armstrong,	„	„ ·9 „
Ditto,	ditto,	100-pounder	„	„ 1·75 „
2½-inch (granite backing)		12-pounder Armstrong,	„	„ ·55 „
Ditto,	ditto,	„ „	„	„ ·6 „
2½-inch (oak backing)		12-pounder	„	„ ·65 „
Ditto,	ditto,	40-pounder	„	through
2½-inch (fir and cork backing)		12-pounder	„	„ ·6 in.
Ditto,	ditto,	40-pounder	„	through

3-inch.—40-pounder Armstrong, 100 yards, not through.

3-inch.—Two 78-pounder shells, filled with sand, at 400 yards, passed through.

3-inch.—Two 78-pounder shells, filled with sand, at 400 yards, just resisted.

3-inch (brick backing).—40-pounder Armstrong, 600 yards, passed through.

Ditto.—68-pounder, penetrated.

Ditto.—100-pounder shell, at 600 yards, penetrated.

3½-inch (brick backing).—40-pounder Armstrong, at 600 yards, no effect.

3·94-inch.—Resisted 14 shots of 30 pounds (English 32·4 lbs.), at 300 metres, in a square metre, (10¾ square feet English).

4-inch.—68-pounder, did not penetrate.

4-inch.—72-lb. shot, just penetrated.

4-inch.—Hollow and red hot shot, little impression.

4-inch.—32-pounder, at 100 yards, sunk deep, but not through.

4-inch, on "Alfred."—Whitworth 68-pounder, at 350 to 450 yards, indent ⅝ inch, bulge 1⅜ inch.

Ditto.—Same gun, wrought iron shot, through, and penetrated 7 inches in oak.

4-inch (+ 6 inches oak and ⅝ iron, "Erebus.")—68-pounder, at 400 yards, penetrated, and did great execution inboard.

4-inch (on oak ship "Meteor."—32-pounder and 68-pounder, at 400 yards and 300 yards, no damage inboard.

4-inch (24 inches oak).—68-pounder, at 600 yards, indented 1 in. to 2·3 in., with cast-iron shot.

Ditto.—68-pounder, at 600 yards, indented 2·2 in. to 2·8 in., with wrought iron shot.

Ditto.—68-pounder, at 400 yards, indented 2·2 in., with cast-iron shot.

Ditto.—68-pounder, at 400 yards, indented 3 in., with wrought iron shot.

Ditto.—68-pounder, at 600 yards., would ultimately destroy.

One 68-pounder does as much damage as five 32-pounders.

4-inch (2 feet 1 inch oak), "Trusty.")—72-pounder cast-iron shot, at 400 yards, broke plate but not scantling.

Ditto.—72-pounder, homogeneous iron, fairly through.

Ditto.—100-pounder cast-iron shot, at 200 yards, did not penetrate.

Ditto.—78-pounder homogeneous shot, through, and 10 inches oak.

Ditto.—100-pounder homogeneous shot, at lower velocity, large fracture.

4½-inch + 4-inch fir.—32-pounder, at 360 yards, indent 2 inches.

Ditto.—68-pounder, at 1,250 yards, indent 1½ inch.

Ditto.—68-pounder, at 400 yards, indent 2½-inches.

Several shot together injured the plates very much.

4½-inch, on timber.—80-pounder homogeneous flat headed shot punched a hole, and 3 inches into timber.

4½-inch, on timber.—Three 68-pounder shot, close together, broke up a plate.

4½-inch, Jones's angular butt.—Took 17 blows from a 68-pounder, at 200 yards, and then the iron was not penetrated.

4½-inch—126-pounder, at 400 yards, cracked and bulged much.

4½-inch.—Two 110-lb. cast-iron and two 126-lb., at 400 yards, quite destroyed.

4½-inch, on "Warrior."—More or less cracked by 68, 100, and 120-pounders, but ribs and inner skin uninjured.

68-pounder,	indented		1·5
	,,	,,	1·8
100	,,	,,	1·3 to 1·9
120	,,	,,	3·1

4½-inch, on timber.—Considered protection against 68-pounders, at 1,200 yards; but 68-pounders, at 400 yards, indented 2·75 inches.

Ditto.—Considered protection against 32-pounders and 8-inch hollow shot, at 400 yards; 32-pounder indented 1¼ to 1¾ inch.

Ditto.—Three 32-pounders striking near each other will break it up.

5-inch plate, on iron sheathing and ribs.	68-pounder shell,	at 200 yards,	indented		.. ..	1·25 in.
	68-pounder shot,	,,	,,	,,	.. .. ..	2·00 ,,
	100	,,	,,	,,	.. .. ..	1·75 ,,
	120	,,	,,	,,	.. .. ..	2·25 ,,

5½-inch.—Resisted 18 shot of 30 pounds (English 32·4) in a square metre (10¾ square feet), at 300 metres range.

6½-inch.—126-pounder cast-iron shot, at 400 yards, indented 1·9 in.
„ „ „ a few shots broke it up.

8-inch, supported by cast-iron and granite
68-pdr. cast-iron shot, at 600 yards, indented 1·25 in.
„ „ „ 400 „ „ 1·4 „
„ wrought iron „ 600 „ broke it up.

As without knowing the velocity of the several shot here mentioned at the time of impact, it will be impossible to make a comparison of the resistance offered in these experiments, a brief abstract of the initial velocities of all the guns in the service has been drawn up, and the loss of velocity in the first thirty yards of flight, as obtained by Navez' Electro-Ballistic Apparatus, is also shewn. This is all that can be given for the present, but by means of this beautiful instrument we shall before long know the velocities of all projectiles at any part of their flight.

Nature of Ordnance.	Projectile.		Charge.	Initial velocity.	Loss of Velocity at 30 yards.	REMARKS.
	Nature.	Weight.				
		lbs. ozs.	lbs. ozs.	feet.	feet.	
10-in. gun, 87 cwt.	Hollow shot	88 5	12 0	1292·3	21·9	Smooth Bore.
68-pr., 95 cwt. ..	Round shot	66 4	16 0	1579·0	25·7	
„ „ ..	Naval shell	51 8	16 0	1809·9	40·5	
„ „ ..	Common shell	49 14	16 0	1790·7	40·4	
8-in. gun, 65 cwt..	Common „	46 0	10 0	1487·9	32·9	
32-pr., 58 cwt. ..	Solid shot	31 6	10 0	1690·0	36·3	
24-pr., 50 cwt. ..	„ „	23 8	8 0	1720·5	41·0	
18-pr., 57 cwt. ..	„ „	17 11	6 0	1690·6	43·8	
12-pr., 18 cwt. ..	„ „	12 10½	4 0	1769·8	51·2	
9-pr., 13 cwt. ..	„ „	9 5¾	2 8	1613·7	49·8	
6-pr., 6 cwt. ..	„ „	6 3¾	1 8	1484 5	49·2	
12-pr. how., 6½ cwt.	Common shell	8 12	1 4	1163·4	39·2	
24-pr. „ 12 cwt.	„ „	16 11½	2 8	1252·7	34·7	
			Drams.			
Wall piece ..	Shot	0 5¼	8	1167·6	32·8	
		Grains.	Drams,			
Enfield Rifle ..	Service ball	530	2·5	1272·8	84·1	
		lbs. ozs.	lbs. ozs.			
6-pr., 3½ cwt. ..	Segment shot	6 0	0 12	946·4	8·9	Armstrong.
12-pr., 8½ cwt. ..	„ „	11 9	1 8	1190·2	9·3	
„ „ ..	„ „	11 5	1 8	1200·6	9·0	
„ „ ..	„ „	11 15	1 8	1242·8	9·6	
20-pr., Land Serv.	Shot	21 2	2 8	1114·3	7·1	
„ Sea „	„	21 2	2 8	997·5	6·1	
40-pr., Land „	„	41 5	5 0	1164·4	6·2	
100-pr. howitzer.	Common shell	103 8	9 0	953·4	4·0	
100-pr. gun ..	Shot	111 6	12 0	1124·7	4·7	
„ „ ..	Common shell	103 8	12 0	1166·1	4·7	
„ „ ..	Shot	174 0	11 0	891·9	2·1	Shot of Capt. Lyons.
„ „ ..	„	150 0	12 0	994·9	3·1	

NOTE.—The mean initial velocity of a spherical shot from the Armstrong 12-ton gun, weight of shot 149·8 lbs., charge 50 lbs., is 1,766 feet per second, and the loss of velocity at 120 feet is 31 feet per second.

With a charge of 40 lbs. the initial velocity is 1,726 feet, and the loss of velocity at 120 feet is 30 feet per second.

Before leaving the subject of these experiments a few practical conclusions may be safely drawn from them :—

1st. That good tough wrought iron of high elasticity, but not necessarily of the greatest ultimate tensile strength, is the best material for resisting cannon shot.

2nd. Rolled iron, although not perhaps quite equal in resistance to the best hammered iron, has great advantages as to cost, if used in simple forms; and a combination of the two processes will probably be found to be superior to either alone.

3rd. Cast-iron and steel, as at present manufactured, are too brittle to be used for directly resisting cannon shot; but a compound structure consisting of masonry, brickwork, concrete, cast-iron, timber, or some such substances, protected by wrought iron armour, may be made of great strength.

4th. Rigid backing is superior to elastic backing, so far as the endurance of the front facing is concerned; but an elastic backing deadens the effect of a blow upon any structure behind it, and upon the fastenings.

5th. The larger the masses and the fewer the joints, the stronger the structure will be, provided that the limits of uniform and perfect manufacture be not exceeded.

6th. The chief difficulty in structures of the nature in question lies in the method of securing the several parts together. This part of the problem cannot yet be said to be fully solved. That fastening is the most perfect which, while being of the necessary strength, involves least difficulty and cost in manufacture, and is least exposed to damage when in its place.

7th. The slight advantages gained in resistance by inclining the surfaces will seldom compensate for the extra difficulty and expense involved in the construction.

8th. Nothing is to be gained by making the mass free to move with the shot at the instant of impact.

9th. Revolving iron shields worked by machinery can be safely made use of, where great lateral range is necessary.

Having dwelt thus long upon the introductory and experimental parts of the subject, it is time now to consider a few matters of practical application.

Iron Embrasures in Masonry Forts.

The first use to which it has been found necessary to turn wrought iron in fortifications is that of strengthening a masonry parapet about an embrasure. It is quite obvious that an embrasure, whatever its construction, must be a source of weakness to a parapet; and it is also obvious that of all parts of a parapet, that immediately about the gun should be the least destructible. With the old flaring cheeks, perhaps, the parapet was less weakened than in any other form of embrasure, but when, with the superior accuracy of all artillery and musketry fire, it became of the first importance to reduce the opening of the embrasure to a minimum, and when the full opportunity of doing this was afforded by Colonel Colquhoun's important invention of the raised racer and imaginary pivot, it soon became apparent that an embrasure could not be made at all strong without the use of a material which holds its strength in less bulk than masonry. This is so obvious by laying down lines on paper representing a parapet of given thickness, and a gun traversing a certain lateral range, that it is not necessary here to discuss it further, but simply to state what appear to be the general requirements of embrasure shields in a masonry fort.

1st. Their strength must be proportioned to the circumstances of the work in which they are placed. It is clear that a shield, which is liable only to a few stray shots, need not be of equal strength with one that is to be liable to a long continued battering; therefore, for simplicity's sake, it is proposed to divide them into three classes.

Class A, to be practically invulnerable.
„ B, to stand several heavy shot on a small area.
„ C, to be just proof against a single heavy shot.

2nd. Their best position is nearly flush with the face of the masonry parapet. Their dimensions depend very much upon the lateral range required of a gun. A gun traversing 60° or 70° requires a shield from 10 feet to 12 feet long to protect the weakened parapet, and a height of from 7 feet to 8 feet will be found sufficient. The port-hole, for any gun at present in the service, will be from 5 to 6 feet of superficial area.

3rd. In Class A and B, at any rate, it has been thought that the shields should be made as independent as possible of the parapet, so that however much the masonry about them should be displaced, they would still protect the gun.

4th. The cost of such shields will vary from £300 to £500 each.

The above refers to embrasures for guns not required to traverse through more than about $\frac{1}{5}$th of a circle, and of not much larger dimensions than those at present in the service; when these conditions are altered some further measures become necessary in reference to the embrasure shield.

In the first place, a wide lateral range involves, it is believed, a moveable shield; and secondly, it entails such an extensive modification of the masonry structure, as almost amounts to a rejection of masonry for the parapet altogether. Supposing, then, that for the present we are dealing with a work whose outer wall shall be of iron altogether, let us consider what had best be done in order to give a very large gun a very wide lateral range. While upon this subject an almost equally important point—namely, that of giving elevation and depression without a dangerous enlargement of port, must be noticed.

Iron Embrasures in iron forts.

First, then, with reference to wide lateral range for a large gun.

Perhaps the most obvious thing to do in this case is to make a shield that would slide right and left a certain distance according as the gun might be directed, and so arranged that either end shall always overlap the iron wall of the parapet. But it will soon be seen that this involves great difficulties, and after all very imperfectly meets the case.

The next experiment would be that of placing the gun with its carriage and platform in a circular revolving tower, the centre of movement being so placed, with reference to the general face of the work, as to admit of the required lateral range; but this involves a very extensive revolving structure and other objections. The least internal diameter that could be given to one of these towers would be about 20 feet, and for the largest guns nothing less than 25 feet or 30 feet would be sufficient.

Again, the old objection of confined space for working the gun, mounting and dismounting it, and contingencies of that sort caused by accident during action, would certainly be raised to this arrangement, while its cost must be very great.

Some simple and more convenient method has therefore been sought for. A small circular revolving shield, with a port the size of the muzzle of the gun on the front side, and an opening on the rear side, equal to the width of the gun's platform has been suggested. The diameter of this revolving shield is such that when it—with the gun—is at its extreme lateral traverse, the opening on the rear side is still within the iron wall of the fort.

It is found that, supposing the necessary strength for this shield, as well as the walls of the fort to be got in a thickness of 15 inches of iron, a 68-pounder gun, having a lateral traverse of 120° or 130°, would require a shield of only 9 feet external diameter, 6 feet 6 inches internal diameter, the face of the muzzle of the gun when run out being flush with the exterior of the shield; the centre of movement of shield and gun would therefore be 4 feet 6 inches from the muzzle, and it would also be about 15½ inches within the exterior face of the walls of the fort.

Sir W. Armstrong's 12 ton gun would require a revolving shield of 11 feet external diameter, 8 feet 6 inches internal diameter, for an equal lateral traverse, and his projected 22 ton gun would require a shield of about 14 feet exterior diameter.

These shields would not have to be more than about 8 or 9 feet high, and would be worked round by hydraulic machinery, with means of moving them by hand in case of accident to the other gear.

But now a few words as to the enlargement of the port in all shields to admit of the elevation and depression of the gun.

By the happy invention of an imaginary pivot at or near the muzzle of a gun, a lateral range of, at any rate, about ⅜th of the circle, is obtained without any considerable widening of the port beyond that due to the size of the muzzle, but the same thing has not been done for the 20th part of the circle through which the gun moves in a vertical plane for elevation and depression.

There have been many ingenious schemes proposed for this desirable object, all based upon the principle of placing the centre of movement in the vertical plane at the muzzle, instead of at the trunnions.

Of course this involves the lifting of a large part, if not the entire weight, of the gun, its carriage and platform, every time the muzzle has to be depressed, instead of the small proportion of the weight of the gun due to the "preponderance" as at present; but with the great facilities given by the modern application of hydraulic power to machinery for raising heavy weights, this obstacle need not stand in the way any longer.

It would be comparatively easy to make the whole of that part of the floor of a fort over which a gun traverses, moveable in a vertical direction by means of hydraulic power, and this movement, if not more than about 2 feet, with a corresponding movement of the gun on its carriage, would at once give the necessary elevation of 12° and depression of 6° or 8°.

Whether the end would justify such means is another question, but it is believed that the time has come when every inch of port opening must be considered, and any arrangement by which it can be reduced to a circular hole little greater than the muzzle of a gun or less than 2 feet in diameter, is at least worthy of notice in a paper upon this subject.

One other method of reducing the height of a port opening suggests itself, namely, by covering a sufficiently large opening in the wall of a fort by an inner moveable shield struck to the curve in which the muzzle moves when elevated or depressed; this inner shield would have an opening of the size of the muzzle and would be raised and lowered with it.

There are difficulties however to contend with in this plan, principally due to risk of derangement by heavy blows.

Iron Embrasures in Earthen Parapets.

It yet remains to inquire how iron may be employed in strengthening an embrasure in earthwork.

It is readily seen that without some addition of strength about it, an embrasure in an earthen parapet becomes such a source of weakness and danger as to condemn the use of earth altogether in these days of accurate fire; but with a proper combination with iron, earth will become a more valuable material than ever.

It is pretty clear that in an earthen parapet, flaring cheeks cannot altogether be avoided, or in other words, the neck and imaginary pivot cannot be brought out to the exterior of the parapet; either the earthwork would be weakened to a very dangerous extent, or the strengthening material would have to be used in such large quantities as to absorb all the utility of the earth.

The best place for the neck is therefore about half-way through the parapet, and in that position there seems to be little difficulty in placing an iron shield which shall give the required protection to the gun and its detachment.

It is not necessary here to define the precise construction of such a shield, it will be sufficient to say that one measuring about 10 feet by 8 feet, with a port, as in other cases, is all that is required; the shield would be made by its own supports in rear quite independent of the adjacent earthwork, only using the weight of what little masonry may be necessary to retain the earth about the gun, for the purpose of resisting the tendency of the shield to move inwards when struck heavily from without.

Other combinations of iron and earth which promise to lead to valuable results are foreseen, but as they are only imperfectly developed at present they will not be further referred to now.

Facing Existing Walls.

The next use of wrought iron to which reference will be made is that of simply strengthening an existing wall of either masonry or brickwork.

Almost any required degree of strength can thus be given to a wall, and upon this degree would depend the method of carrying it out.

Two or three different ways of doing it are here suggested. The most obvious way is to bolt plates upon the wall; but in the case of an existing wall this is not a very easy thing to do. Piercing a masonry wall with a vast number of large iron bolts would be very tedious and expensive. In that case one might either attach to the wall a wrought iron boiler plate caisson, held on by strong bolts at wide intervals, then attach the armour to the caisson, and fill the caisson with concrete; or else take down the front part of the wall, say to a depth of 3 or 4 feet, and build in at that depth strong irons, themselves held back by a few bolts to the back of the wall, and the armour would then be bolted as frequently as necessary to the irons, as the rebuilding of the wall went on. This would be much the same as was done with the brickwork at Shoebury, before described. In the case of stonework, and especially of granite, the position of the bolts and joints of work must be made to agree, so that the stones shall be pierced as seldom as possible, and even layers of brickwork might be built between the courses of the masonry, through which the bolts might pass, so as to avoid making any holes through the stones. There are many other minor points to be thought of, but which present no very great difficulty. As to the cost of this, it is difficult to give accurate figures, but taking a wide range, it would vary from £2 per foot superficial of wall made tolerably strong, to £5 per foot superficial made invulnerable.

Partially Facing Walls.

From what was observed at Shoeburyness, on the occasion of firing at the brick wall faced with armour, one is disposed to think that a masonry wall might be made exceedingly difficult to breach with the expenditure of very limited quantities of iron upon it. Even when the armour plates had been carried away, and the brickwork immediately at their back destroyed, there was still a great deal to be done before making a practicable breach; there was a complete network of iron bolts and bars that no number of shot or shell would clear away, and these held together irregular masses of brickwork that would prove extremely troublesome to remove. Even a number of bolts with large wrought iron washers, built into a wall at intervals, and passing right through it, with occasional beams or girders laid horizontally, would add immensely to its strength at comparatively a low cost. One other suggestion that presents itself is that of strengthening a wall with planks of iron at intervals over its face, which would give great strength at a greatly reduced cost. No more will be said upon the mere coating a wall, although it is a grand field for invention. Actual trial by artillery fire is the only method of determining the value of any particular principle, and it is hoped that some of the many ways that suggest themselves will be put to that uncompromising test.

One other point in this section of the subject should be mentioned, viz., the construction of detached walls. Great facilities exist for building an independent iron wall, having its supports part of its construction, and there are many ways that can be suggested for doing this; but it would occupy too much space in this paper to describe them.

Iron Traverses, &c.

Before leaving this part of the subject, let us briefly refer to one use for wrought iron which seems worth considering, viz., for traverses, splinter proofs, and expense magazines. Traverses have been frequently complained of as occupying valuable space and being cumbrous. Now this might be entirely corrected by making them of wrought iron. A simple wall of wrought iron would have the great disadvantage of causing a shot to break up into splinters; but this difficulty would be obviated by composing the traverse of a strong wall of wrought iron, protected on the enemy's side by a sheathing of $\frac{1}{2}$-inch boiler plate, at a distance of 2 or 3 feet from it, the intervening space being filled with sand. By this means the traverse would not be more than 3 feet 6 inches thick. A shot or shell would readily pass into the sand, the former would most likely give out no splinters at all, the latter would do some damage of course, but not much; even a sod revetment on the enemy's side would perhaps suffice. The same remarks apply to splinter proofs and magazines.

Construction of Iron Forts.

We now come to the question of *Forts and Detached Works* constructed entirely of iron, and contrary to what might at first sight be expected, all difficulties of construction are wonderfully diminished when the ordinary materials in use are excluded. It is really difficult to design a fort composed partly of iron and partly of masonry—that is to say, to put a masonry fort in armour, and to work up all its parts into one consistent, uniform, and sufficient degree of strength; but it is comparatively easy to design a real iron fort. There is no material of such uniform and reliable strength, and so easily applied in any forms or dimensions, as good wrought iron, and, therefore, there is no material that will afford such facilities for putting the strength of a structure where it is most required, and of avoiding superfluous strength in its less important parts.

This is not the place to discuss at any length what particular positions appear to require iron forts. In the defence of coasts and long lines of frontier, there will always be important points which must depend more upon their own strength than upon any external support they may receive. Such positions we find in a very marked manner on our own coasts, and especially where our principal naval dockyards and arsenals occur. In these places the great problem is how best to defend a certain channel, or other means of approach or landing place, or to occupy ground which could in any way be turned to account by an enemy, by a work that shall in itself be secure against any sudden surprise, and at the same time be capable of resisting the heaviest battering; and this cannot be done with one-half the effectiveness, and for the same money, with any other material than wrought iron.

The experiments described in this Paper prove that a wrought iron fort can be built of any strength; but it is not so clear yet that it can be done at reasonable cost. The great difficulty in comparing the value of an iron fort with that of one of masonry is, that no masonry fort that has ever been built, is proof against cannon shot; of course, in nine cases out of ten, they are not wanted to be absolutely indestructible; whereas, an iron fort can, undoubtedly, be made perfectly invulnerable. The only plan, therefore, will be to take the strongest masonry fort that can possibly be built, and an iron fort of medium strength, and compare the cost of these two.

Now, the first element of saving in an iron fort is the reduction of bulk, and this appears in a very remarkable degree. In one design of an iron circular fort, mounting 42 guns, prepared with a view to compare the space it would occupy with that taken up by a masonry fort of equal armament, it appears that the outside diameter of the former would be about 140 feet against 190 feet for the latter, or, in other words the superficial ground area of the one would be to that of the other as 1 to 1·8 nearly; and although of two forts of the same construction, the one, having the guns more dispersed and fewer in proportion to the extent of the wall, might have the advantage, especially if the embrasures were large and flaring, yet with the very small modern embrasure, and the strong iron face, nothing is to be gained by separating the guns by large intervals. Another element of saving in iron forts might be the reduction in the internal height of the chamber or casemate in which the guns are mounted. An iron fort ought to be constructed [so as to be more like the gun deck of a ship of the Warrior class. Her guns are 15 feet 6 inches apart, and there is 6 feet 6 inches headway between the deck and beams. This may be somewhat too little for a fort in which the heaviest guns may come to be mounted, but 18 or 20 feet, from gun to gun, would be ample in the construction proposed, and if the guns were mounted as they are in the Warrior, namely—upon ships' slides instead of upon traversing platforms, or better still upon compact wrought iron carriage platforms of special construction, 7 feet 6 inches headway would be ample ; of course, some mechanical contrivance would be required to traverse the slides easily, but nothing could be more simple than to afford this.

In thus reducing the height of the casemates of a fort, it would, of course, be necessary to see that the entire height is not left so small as to facilitate escalade. In forts on land this would be provided against by means of a ditch ; and in sea forts other obstacles against mounting the sides of the work would easily be found.

Another great element of saving is in the comparative weights of an iron structure and one of masonry. This, where there might be great difficulty in giving foundations, would be of serious importance.

The general principles upon which it is thought an iron fort should be constructed would be these. The form need not be here defined, but it is assumed that they will almost always be casemated, and quite bombproof. There should be a skeleton structure covered on its sides by a coat of armour. The strength of the former should not at all depend upon the latter ; it has to support the floors upon which the guns are mounted, and, if it be a casemated work, it has to bear the weight of the bombproof construction ; therefore, it should be so placed as to be affected as little as possible by any hammering that the armour may receive. The piers or columns of this skeleton structure might be of wrought iron boiler plate cylinders, filled with concrete, the concrete to bear the pressure of the weight supported, the wrought iron cylinder to keep the concrete together, and only to be under tension. It is calculated that no end of strength may be obtained at a low cost by these cylinders, and they occupy but little space. Where other forms than a cylinder might suit the internal arrangement of a fort, there would be no objection to them, so long as the strength of iron covering is proportioned to the strain to which it may become liable.

The rest of the skeleton structure would consist of wrought iron built up girders, carrying the gun floors, filled in between with concrete arches, assisted by wrought iron curved plates, and the bombproof roof would consist of curved wrought iron ribs, having a strong skin of wrought iron plates over them, and the whole covered with a few feet of earth.

It is not intended here to determine what the structure of the armour shall be; that must alone depend upon further experiments. Fortunately, the question of an iron fort does not entirely depend for its existence upon this matter of detail. Whatever the armour may be, it should be of such construction that it shall be easily repaired and strengthened at any future time, when the march of gunnery may demand it.

It may be fairly assumed, that for the present generation at any rate, an invulnerable coat will be got in about 12 or 15 inches of iron, or by some equivalent compound construction of armour and backing that will be equal to about that weight of iron. If the fort should be of more than one tier, the armour of each tier should be made independent of that of the tiers above and below, so as to make as local as possible any injury that may be received. If guns are to be mounted on the upper platform or roof, the armour can be readily continued up, and an internal skeleton structure provided for its support.

Iron Screens in Casemates.

The absence of the massive masonry piers hitherto existing in casemated works, may, while it adds much to the facility of all operations of the gunners, yet expose them more than hitherto to the explosion of any shells that may enter, and to splinters of shot; but it is proposed to meet this by the use of portable wrought iron screens, of some very simple construction; and, of course, to make the place habitable as a barrack, wooden bulk heads would be necessary, these to be entirely removed when clearing for action.

Gun Casemates of less depth.

One other suggestion is offered before closing this part of the subject, and that is, that in some positions, at any rate, the casemates should be constructed of only just sufficient depth to give cover to a gun and the men working it.

Suppose this could be done by a casemate 20 feet deep, what an immense saving would be effected! And with some little arrangement by which each gun might be supplied with ammunition and stores, by its own particular hoist from the lower or basement floor, many of the disadvantages of this reduction would be met. Where barrack accommodation would be of importance in peace time, the deficiency of room in the casemates might be met by providing cover by light roofs of ordinary fire-proof construction, and in either case a strong gallery communicating with the rear of the casemates for the general purposes of the fort would be provided.

Form of Iron Forts.

Next as to the general form of a detached iron fort; this of course must mainly depend upon the position it has to occupy and the particular purpose for which it is intended. A circular work naturally distributes its fire equally in all directions, and, therefore, for a fort out at sea, or in any open space equally assailable on all sides, this might be the most perfect form. A circle also gives greater internal space than any other figure of the same periphery. But even with a circular iron fort, the strength of any part of the circle may be proportioned to its particular exposure to attack, and in the case of a chain of circular forts this might be worth remembering. In other positions a flattened circle, or an ellipse, might be the best form; and in one case a sort of rounded off star shape was found to afford great facilities of construction. However, there is really no general law to be laid down as to the form and size of these iron forts, any more than in the case of works constructed of other material.

Cost.

Before leaving this subject of detached iron forts, it may be well to say a few words upon the matter of cost. It is always unpleasant to be reminded of these grosser considerations; but in fortification, as elsewhere, money is an object, although not the first, and, therefore, this side of the question must be briefly touched upon here.

It is not intended that too much reliance should be placed on the figures here given, but it is thought that they shew some sort of approximation to the probable cost of the structures in question.

The cost of a wrought iron circular fort of a total diameter of 192 feet, mounting 120 guns, in four tiers, depth of casemate 32 feet, was found to be £1,315 per gun, measuring upwards from the under side of the lowest gun floor. And the cost of a similar fort, mounting 60 guns, of a total diameter of 96 feet, was found to be £1,100 per gun. Also a fort, mounting 128 guns, was estimated at £1,263 per gun; and one, mounting 42 guns, as nearly as possible the same. Now we shall not be far wrong in saying that a corresponding masonry fort, including foundation, in any position involving much difficulty in foundation, would cost nearly £1,200 per gun; and if we suppose the foundations to come to about £200 per gun, in a masonry fort, it will be little more than £100 per gun in an iron fort, which, added to the above prices of iron forts exclusive of their foundations, gives a price varying from £1,200 to £1,415 per gun. In the case of a fort out at sea there must be added to both stone and iron forts a certain sum per gun to cover the heavy cost of raising the lower tier of guns a proper height above high water mark, (the lower gun ports are supposed to be not less than 25 feet above low water mark), and of making a strong wall down to low water mark. This in an iron fort is roughly assumed at £400 per gun, and in a masonry fort at £200 per gun; so that the cost of an iron fort at sea would vary from £1,600 to £1,815 per gun, against £1,400 per gun for a masonry fort, while, as shewn already, the relative costs of an iron fort and a masonry fort on land would be as about £1,300 to £1,200 per gun.

Strengthening Fronts of Existing Fortifications.

We next come to the strengthening of parts of an existing front of fortification. And here again, as with a compound masonry and iron fort, great difficulties occur.

But disregarding for the present all minor obstacles, let us look to the simple strengthening, by some of the means before alluded to, of those parts of a front which have hitherto been readily breached.

Taking a Modern Front as a type of the bastioned trace, we see that in an attack, it is necessary to advance upon two ravelins, breach them somewhere near their salients, then, having a certain advantage there, to commence breaching so much of the faces of the bastions as can be seen down the ditches of the ravelins—to continue the advance upon the bastion, and having arrived at its salient place of arms, there to establish breaching batteries, and batter down so much of the faces and shoulders of the bastions as may be necessary. If this be not the precise course, something equivalent, or some part of it must be done.

Now, if it be worth while to do anything to a fortress to give it greater power of resistance, select that side which is most favourable for attack, and make the salient of the ravelin proof against breaching batteries; and not only that, but mount in that salient of the ravelin, one or two good shell guns, in such a way that they shall command all the glacis of the front, and be safe from any injury themselves. This would, most likely, be effectually done by means of a circular revolving iron tower, with underground communication with the place. The salient of the ravelin would thus be made a secure outwork in itself, which, by means of its guns and riflemen, would prevent any advance upon the place so long as it held out; its gorge would, of course, not be so strong as to make it capable of holding out against the place if captured by any bad chance.

The worst that could happen to this salient, then, would be to have it all blown into the air, by means of mines; but we should provide against this, by placing so strong an iron gallery at the back of the counterscarp, as should resist all mining; and this power of meeting underground attacks by means of masses of wrought and cast iron enters into all the arrangements here discussed.

This is the first process of strengthening; the next would be to place armour upon such parts of the bastions as could be most easily breached. This need not be dwelt upon at any length; it would be costly, no doubt, but not beyond the object gained; a masonry fortification unprotected by armour is very costly. The cost of a bastioned front has been variously estimated at from £50,000 to £70,000, and few of the modern German fronts are under £50,000. Does it seem unreasonable, then, to spend £10,000, £20,000, or even £30,000 upon a front, in making it equal to resist an attack of twice the duration of that it could now withstand? remembering that such additional strength might just turn the balance against its being attacked at all. It is not supposed that there is any fortress in the world the whole escarp of which it could ever be necessary to cover with iron armour. It would be absurd to argue in favour of that. Some 1,200 or 1,500 feet per front, at £100 per foot lineal, would put it out of the question; but a strengthened salient of a ravelin and armour on part of the faces of each bastion is not unreasonable where great importance may be attached to a fortress. In connection with this subject it is worth while considering whether it would not be possible to prepare an escarp wall in such a way that armour could be attached at short notice, if required, at any future time.

There are many other parts of a front of fortification in which iron would be of immense importance.

The caponiers should certainly be put in armour, if not constructed of iron altogether.

All guns mounted en barbette, should be protected by revolving wrought iron screens, if not covered by a complete tower. In fact this material would be turned to a thousand uses, in such things as cavaliers, epaulments, mantlets, and screens of every description during the whole duration of a siege, finally giving the besieged immense advantages over those now possessed in their critical efforts to resist the assault of a breach.

It may be said that we are dealing with the easiest problem when we take a bastioned front of modern and regular trace, but it is only assumed by way of roughly explaining what might be done under more difficult and varying circumstances. For instance, suppose we take a modern elongated polygonal front; the salient parts must be advanced upon, therefore, something corresponding with what is described for the salient of the advanced ravelin of the bastioned front might be adopted here. Casemates would have iron fronts, caponiers particularly would be in armour, and such parts of the escarp as could be seen, or if not seen, would be liable to be breached, would receive more or less protection from armour. Every description of fortress would require its own special treatment; and there are none that could not be more or less strengthened by armour judiciously applied.

Breaching. Before finally leaving this part of the question, let us look a little more into the past history of breaching. We read that, taking an average of nine operations during the war in Spain (1812 and 1813) by batteries at distances of from 450 to 620 yards, a practicable breach of 103 feet wide was made with the expenditure of about 100 rounds per foot lineal of breach. The iron thrown at these walls would have covered the areas breached with a plating about two inches thick all over. This enormously high average was greatly due to the distances from which the breaches were made, and other disturbing causes.

At Antwerp, in 1832, a breach was made practicable by 1,200 24-pounder shots, at 40 yards, or with 15 rounds per foot lineal; at Metz, in 1832, two breaches were made with 2·8 and 4 rounds respectively per foot lineal; at Juliers, in 1860, breaches were made practicable at short ranges of 60, 80, and 96 yards, with 2, 4, and 5½ rounds per foot lineal; and at Eastbourne, in 1860, a breach was made by about 2 or 3 rounds per foot lineal. I think, therefore, it may be safely assumed that 15 rounds per foot lineal from modern breaching guns, at short distances, will bring down any masonry wall. Now, suppose a wall to be 30 feet high, and that it is not necessary to fire at a point lower than 6 feet from the foot of wall, or higher than 10 feet from the top of wall, the above named 15 rounds will be dealt upon a superficial area of 14 feet, or 1 shot to every foot superficial; and you will see by the experiments above described that it will not be difficult to keep out that, and a much greater number of shot, from the largest breaching guns.

Iron Fortress. Finally, we must briefly touch upon the subject of a complete iron fortress; and it must be repeated that not only would it be possible to erect an impregnable iron fortress in almost any position, but also that such a thing is practicable in every sense; costly it may be, when compared with defences of the present construction, but not so when compared with the object gained.

For every £1,000 now spent in building works, which are only expected to stand a siege of weeks, we might spend £2,000 in building a fortress that would never fall; a casemated, bombproof, impregnable Gibraltar. Sums almost fabulous, have been spent in times past, in partially securing the frontiers of a state, or in defending a naval arsenal or depôt, and it is not absurd to say that, for the future, somewhat larger sums, but yet sums less enormous, when compared with the increasing wealth of nations, shall be spent in making these positions perfectly secure; and this can *best*, if not *only*, be done by means of iron.

Now, although so decided an opinion is here advanced as to the feasibility of these iron fortresses, it is not to be expected that any well-matured scheme can at present be given for one of them. It will be enough if a few general ideas upon the subject be thrown out for the consideration of those who may feel interested in it. The elaboration of these ideas must not be attempted without long and attentive study, guided by the experience of a far more extensive set of experiments than has yet been made in this or any other country.

First suppose the case of a very large casemated bombproof iron circular fort, secure against reverse fire, all the outside face very strong indeed, but as little as possible exposed to view from a distance, very secure against escalade, with a deep wet ditch, all magazines and stores especially safe from vertical fire, also made secure against mining by means of deep impenetrable masses of iron at the back of its counterscarp; suppose such a work mounting a large number of guns with every advantage that modern science will afford; and suppose, further, that at certain distances in front of such work there were shot and bomb-proof iron towers, secure against surprise, with guns pointing inwards only, and that these towers had underground communication with the place by means of iron galleries; how would such a place be taken, so long as its stores and ammunition held out?

Again, suppose the angles of a polygon were occupied by invulnerable iron bastions, connected by curtains composed of detached walls of iron, with earthen-work in front of them, with wet ditches and detached towers as before; and suppose, further, the centre of the polygon to be occupied by a strong iron citadel, how would a besieger set to work?

Having thus imperfectly traced our subject through a general argument as to the advantage of using iron for the purposes of defence, and a short history of the experiments which have an important bearing upon the question, with some practical suggestions as to the application of what we have learnt from those experiments, it is felt that we have now arrived at a point beyond which it would be presumption, at present, to proceed.

The consideration of this important question will, therefore, be here brought to a close.

PAPER XIV.

ON CONCRETE AS A SUBSTITUTE FOR BRICK AND STONE MASONRY IN WORKS OF FORTIFICATION.*

By CAPTAIN SCOTT, R.E.

"The most costly part of permanent fortifications is the masonry, which is, therefore, always kept at the lowest point consistent with a tolerable security. Scarps are frequently kept at a reduced height, and casemates and bombproofs omitted, in order to avoid as much as possible the expense of masonry."

"The masonry of a fortress is also the most tedious part of its construction, and is for this reason, of necessity, omitted in all works where expedition is a *sine quâ non.*"

"If we inquire into the reason of this twofold objection to the use of masonry in situations where it would otherwise be most desirable, it seems to be, that while the earthwork can, by means of rails and trucks, be almost, as it were, done by machinery, the whole of the masonry must remain as completely hand labour (and skilled labour too) as in the erection of the smallest edifice. Is it then possible to give to the masonry of the scarps and casemates of a fortress such a character as shall take it out of the category of tedious and costly hand labour, and render it capable of being executed in gross by the aid of machinery and unskilled labour?"

An attempt will be made in the following paper to shew that this is possible to a large extent by substituting for the brick and large stone masonry of our fortifications, a cheaper description of rubble work, such as we now term concrete. At the present moment there seems to be a strong feeling abroad in the country that soldiers might, with advantage to themselves and the state, be employed on works of construction, and a committee has recently enquired into the advisability of teaching them trades, in order to give them occupation. The substitution proposed would not only effect a great saving in point of material, but, from requiring little skilled labour, would provide our men with a description of work which they could execute without previous instruction.

There is nothing new in the idea of using concrete for revetments, magazines, and bombproofs. The proposition has been made more than once, and very recently the use of concrete for revetments has been strongly advocated in a paper, from which the above quotation is an extract, by Captain Fowke. This paper was circulated through the corps by the Inspector General of Fortifications, who expressed himself favourably concerning the proposition, but asked the opinion of his officers upon it, and the idea would probably have received more attention from them, but for the erroneous ideas concerning the capabilities of concrete as a substitute for brickwork and other masonry, which have been derived from the works of Sir Charles Pasley, and from a failure which occurred in an attempt to introduce its use in situations for which it was unsuited.*

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* This Paper was read at the Friday Evening Meeting of the R. E. Officers at Chatham, March 28th, 1862. A portion of the Appendix then published, has been incorporated with the text, or introduced in notes, and one or two inaccuracies have been removed.

In endeavouring to place before you the position to which concrete is entitled as a means of construction, I propose, first to call attention to instances of its use both amongst the ancients and in recent times; then to endeavour to remove the unfavourable opinion of it to which Sir Charles Pasley and others have been led; lastly, to shew that we should be fully justified in introducing it largely into fortifications, and that the saving which would be effected by doing so in the works we are now constructing merits the attentive consideration of the corps of Engineers.

The term concrete is of recent origin. According to Mr. Godwin it is derived from the Latin word "concresco," signifying to grow together, to congeal, to clot, and it may be applied to any construction of small irregular stones united without arrangement,† by a cementing material semi-fluid when first used. Understanding the word in this general sense, and not confining it to cases in which the stones and lime are turned over together with a shovel or otherwise, as is now done for foundations, the use of concrete in building is evidently of very early date. De la Faye asserts, and in this view he is supported by Fleuret, that the Great Pyramids of Egypt were constructed with artificial blocks of small stones and lime, and that the large stone over the tomb of Porsenna, and the stones which crown the walls of the ancient Heliopolis, are of similar construction.

M. Fleuret says that the art of building with factitious stones was in use with the Babylonians also, and he quotes Pliny to prove that the columns of the peristyle of the Egyptian labyrinth were artificial, and asserts that the small pyramid of Ninus was formed of a single block.

Without, however, giving much weight to these instances, there is abundant evidence to shew that the method of building by concretion was extensively used both by Greeks and Romans.

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* Concrete is, however, only underrated as a substitute for brickwork in walls of buildings. For foundations much more reliance is placed on concrete of very weak hydraulic lime than it merits. Fortunately, it is usually confined in such cases, and its want of transverse resistance is comparatively unimportant.

† In the enumeration which follows no instances have been cited which, so far as I have been able to ascertain, can be classed as "rubble work," in the ordinary sense of the term. Rubble work requires some little skill in arranging the stones; to build a good rubble wall in lime mortar is work for a clever mason, but when the stones are thrown into a casing at random, either mixed with mortar beforehand or grouted subsequently, the commonest labourer will do the work as well as an expert mechanic, and the same may be said if the small pieces of stone are placed in moulds by hand, as was much practised by the Romans.—H. S.

At the pass of Thermopylæ some of the walls are constructed of small stones and mortar. At Tharsalia and Messene there are many instances of the use of a shell of masonry, filled in with pounded bricks or tiles, rough stones or flints, and lime, well incorporated. At Messene, indeed, the wall surrounding the town is wholly of this description of work. The method of building was termed "emplecton," and it is found that it was employed in most of the ruins of the ancient buildings of Rome, the stones used being small shapeless pieces not bigger than the fist, such as we should reject for our most ordinary constructions. Of such materials, however, as we learn from Rondelet and other writers, were built the Palace of the Emperors, the Golden House of Nero, the Temple of Peace, the Pantheon of Agrippa, the Temple of Augustus, the Colosseum, the Baths of Agrippa, of Titus, of Dioclesian, the aqueducts of the city, and the greater part of the theatres and amphitheatres; indeed, "so generally was it used," "so favourite a mode of construction did it become from the astonishing solidity which it conferred, that there are few remaining Roman monuments in which, either in the foundations, in the shape of walls, of pavements, or of water tight linings to tanks, &c., which endure remarkably well to this day, it may not be found."* Where parts are gone it is evident, says Rondelet, that violence has been used to destroy the walls, since those which have been deprived of their facings have remained in this condition for nearly 2,000 years.

The Great Wall of China, it is said, is built, in part at least, in a similar manner, and is in a perfect state of preservation.

The Romans brought their mode of building to England, and the Saxons and Normans followed the examples they found. Among Saxon buildings, Godwin names as being built of what may be termed concrete, portions of Richborough Castle; the walls of Aldborough Church, Yorkshire; the towers of Earls-Barton Church, that of St. Peter's Church at Barton-upon-Humber, Lincolnshire; and a building at Warnford, near Southampton; and they are still, the same author states—"of amazing solidity and appear to defy time." He says, "that they are composed some of round pebble stones united by mortar, and some of rubble stone and flints well grouted, and that the Normans often constructed buildings entirely of rubble stone or pebbles rendered into a mass by lime."† Sir Charles Pasley confirms this. "It must be allowed," he writes, "that not only the ancient Romans, and after them the Moors, but even the Norman Barons of England in their feudal castles used concrete, of which Kendal Castle is one of the most striking examples."‡

Smeaton having observed a portion of the outer wall of Corfe Castle in a remarkably leaning position, like the tower of Pisa, was induced to examine it, and found the interior filling of the walls to be of rough rubble and fragments from the quarries cemented with a mortar composed of lime, " doubtless originally of good quality," and a considerable admixture of sharp sand and pebbles, which had evidently been poured in in a fluid state.* From what he saw here he adopted a similar method of building the rubble backing of the first lock on the river Calder.

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* Godwin on Concrete. Transactions of Institute of British Architects, Vol. I., part 1. The concrete, according to Vitruvius, consisted of a cement of five parts pure sand and two parts lime, with which, when well incorporated, were mixed pieces of stone weighing each about 1lb. Pliny says, to make good cisterns the cement should be composed of five of fine sand and gravel to two of lime, none of the stones exceeding 1 lb. in weight. To increase its solidity he recommends beating. These materials were sometimes rammed in an encasement, such as is used in Barbary and Spain for Pisé work, and sometimes thrown at random between castings of brick and stone.—H. S.

† Godwin on concrete.

‡ Pasley on Limes and Cements. Note, page 16.

M. Rondelet states that the columns of the choirs of the Church of Véselay, in Bourgogne, were ascertained to be of artificial stone by Marshal Vauban, and that the pillars of the Church of Saint Amand, in Flanders, were made in the same manner. He tells us also, that at Lyons, concrete is used for wharf walls and the piers of bridges, and that with the Metz lime concrete arches may be constructed without bricks or stones, and these arches will form a single piece as hard as stone.

Belidor states, indeed, that in Metz most of the cellars are so constructed; the gravel used is from the river; and he says, that when set the concrete will resist steel-pointed tools.†

According to Sir William Reid, the walls of the fortress of Ciudad Rodrigo, in Spain, are of concrete, the marks of the boards, which retained the semifluid matter in their construction, being everywhere perfectly visible. Besides sand and gravel, round boulder stones were employed.‡ These were from 4 to 6 inches in diameter, procured from the ground around the city, which is everywhere covered with them.

The Bridge of Lladonet, six leagues from Barcelona, consisting of two rows of arcades placed the one on the other, was entirely constructed of concrete. One of the lower arches gave way from the work being carried up too hastily, and the work was abandoned, but M. de Betancourt resumed it, and raised the bridge to a height of 150 feet, on a length of upwards of 700, with perfect success.§

Treussart relates that the Italians at Alexandria make very good concrete blocks with the Casal lime, and employ them in angles; they are 4 feet 8 inches long, 2 feet 8 inches wide, and 2 feet 8 inches high; they are buried under ground for two or three years, and there attain great hardness. He says that Colonel Finot constructed at Strasburgh an arch of concrete of 13 feet 4 inches span, which succeeded very well; and that a similar arch was constructed at Schelestadt.‖

Nearly thirty years since the sea wall at Brighton was constructed of concrete composed of a weak water lime from Bycombe. The section of the wall is 2 feet 6 inches thick at the top, upright at back, without counterforts, and battering in front with a slope equal to one-third the height. The foundation goes down to the chalk, and from the top to the bottom it is in one part 70 feet high, in many 40 feet. This wall was perfectly successful, and is now in a good state of preservation. An account of it by the late Colonel Sir William Reid is to be found in the first volume of the Corps Papers.* A row of houses was also constructed about the same time according to Mr. Ranger's patent process, the peculiarity of which consisted in using hot water. The walls are 50 feet high from the bottom of the cellars to the top; they are 20 inches thick at bottom, the greater part being of the patentee's artificial concrete blocks; but much is also made like the sea wall between two sets of boards. The arches of the cellars are all of concrete made of sea gravel. The lime used was from Lewes.

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* Smeaton's Narrative. Book 2. Chap. 3. Par. 98.

† Belidor. " La Science des Ingénieurs." Livre III. " Elle," (the Metz lime) " fait un si bon mortier, qu'à Metz presque toutes les caves en sont faites, sans autre mélange que de gros gravier de rivière; il n'y entre ni pierre ni brique, et cela fait un mastic si dur, que les piques les mieux acéréesn'y peuvent mordre, lorsque ce mortier a fait corps."

‡ Corps Papers. Vol. I. Notes on Concrete, p. 27. Note.

§ Raucourt de Charleville. L'art de faire de bons mortiers. Note, p. 296.

‖ Treussart. Essai sur les mortiers. Sect. 2. Chap. XV.

Numerous examples of the use of Mr. Ranger's artificial blocks exist also in and around the metropolis, amongst which may be named Nos. 16 and 17, Pall Mall, which are faced with the concrete, and a proprietary school at Lee. When the latter building was examined by Sir William Denison some years afterwards, the concrete at the ground line, where the drip of water had acted, was soft,† and yielded easily to any force applied, but the walls above were very fairly hard and seemed to have stood well.

About this time Mr. Taylor, then architect of the Admiralty, proposed to the Lords Commissioners to build not only docks but wharf walls with Mr. Ranger's concrete. Their Lordships having approved of the trial being made, the experiment was carried out both at Chatham and Woolwich. The docks were faced with granite, but the concrete of the wharf walls was exposed to the action of every tide. The Woolwich wall was in part built with concrete thrown in in mass, as with the sea wall at Brighton, and in part with concrete formed into blocks, which were allowed to set and harden before being built into the wall. At Woolwich, both the blocks and the rough concrete were composed of lime and gravel in the proportion of 1 to 7, brought to the proper consistency with boiling water; but the blocks were supposed to be made of Aberthaw lime, while Dorking lime was to be used for the rest of the work. "During the hard frost in the winter following, evidences of failure began to shew themselves; and as soon as the thaw allowed a thorough inspection of the face of the wall to be made, it was found that hardly a single block had escaped without some damage; in many instances the whole face had peeled off to the depth of half-an-inch, and at one spot, where a drain discharged itself into the river from a height of about 6 or 8 feet, the back action of the water after its fall had worn away the lower courses to the depth of some inches; these were the evidences of the action of frost and water combined upon the best constructed wall at Woolwich. At Chatham they were of the same character, but the damage done to the wall was much greater. The portion of the river wall at Woolwich which was built with rough concrete had been severely injured by the common action of the water before the frost, and the latter had only caused the destruction of the face to proceed with greater rapidity."*

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* In one or two places, where the pebbles are thrown against it by the sea the face is somewhat damaged, but the injury so done is very trifling, and the chief part of it stands well. Here and there there are evidences of settlement and also of faulty construction. One can see generally the levels at which the moulds in which the wall was built were moved, as there is a deficiency of mortar at these points. This defect admits of easy remedy in future constructions.—H. S.

† It may be seen, on examining brickwork buildings in Halling or Dorking lime mortar, that the mortar always perishes in the joints at and near the ground lime.

On 2nd February, 1835, a concrete bombproof was commenced in Woolwich marshes by Mr. Ranger. The vault was 18 feet long and 6 feet thick immediately over the crown of the arch, where it was formed with a ridge in the usual manner. The piers which supported it were 8 feet wide and about 4½ feet high to the springing of the arch, having foundations 10 feet wide, with an offset of 1 foot on each side. The arch was completed on the 17th March following, and on the 21st March, 1835, the centres were struck. The piers then gradually commenced to sink into the soft spongy peat on which they were built, and settled at irregular periods to a depth of 11 or 12 inches, causing a small crack or fissure in the crown of the arch.

In the following May the bombproof was fired at both with shell and shot; and a committee of Artillery and Engineer officers reported to the Master-General that, "considering the disadvantageous ground on which it was constructed, which had occasioned some degree of settlement, it sustained the effect of the vertical fire directed against it in a very satisfactory manner, and they entertain every hope that Mr. Ranger's concrete will be found available for magazines of small dimensions, casemates, and those parts of revetments in fortresses which are least exposed to the effect of shot; but with the limited scale on which this experiment has been carried on, the committee do not think, at present, they would be justified in recommending its application in the construction of large powder magazines." The lime used in this experiment was from Dorking, and the concrete when fired at was still damp and friable, except on the surface.†

The river wall of the Chelsea water works, at Kingston, is constructed of concrete made of 1 part Dorking lime and 11 sand and washed shingle. The wall is 1,200 feet long and 25 feet high.

About three years since a small hut was built on the sloping ground to the north of Brompton Barracks, of Taylor's facing bricks, backed with Scott's cement, the proportion being 1 of cement to 9 of gravel. Though the concrete was only 7 inches thick, plastered over with about three-quarters of an inch of the same cement and sand, and the wall was carried to a height of between 7 and 8 feet, it stands remarkably well. Similar concrete was used by Mr. Taylor for walls of houses at Roupell Park.

In the paper by Captain Fowke, already alluded to, mention is made of a hut work-shop constructed of concrete poured in between boards, forming a mould, as is done with pisé work in the south of Europe. "The concrete was made of the ordinary gravel of the district,‡ (containing about ⅓ sand), and the cement known as Scott's cement, in the proportion of ten of gravel to one of cement; this was mixed to a proper consistency with water and thrown in, as stated above. It set firmly in a few hours, and although it was tried by a hard frost during its construction, and has been quite exposed to the still more severe frost of last winter, it has not suffered in the least, and has gone on hardening till it now presents almost a monolithic surface." In a paper furnished at the request of the manufacturer of the cement, Captain Fowke says, "The concrete made with it has been used here* in most trying situations; in one case, when a building stood on a concrete foundation of 6 feet in depth, it was resolved to excavate for a basement, and the ground was removed to the entire depth of the concrete for a length of 120 feet, and remains so to this day, without symptom of failure or settlement."

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* Corps Papers, Vol. 2. Notes on Concrete, p. 264, 265.

† The proportions were 7 parts of mixed gravel and sand (about 5 gravel to 3 sand), 1 part of lime and 1½ parts of boiling water. The piers were raised in layers of 1 foot, and the arch, begun from both sides, was completed in layers forming 11 voussoirs.

‡ South Kensington.

"In concrete pisé an engine house, 20 ft. × 12 ft. on plan, was built of the same cement concrete; the walls were 9 inches thick, and were carried up perpendicularly to a height of 6 feet from the ground, at which height a semi-circular arch, 9 inches at the haunches, diminishing to 6 inches at the crown (also of concrete) was thrown across, and this is now standing without outward thrust or sèttlement. Ordinary brickwork would not have stood this test, and would have cost more than double the price."

Since this, Captain Fowke has built two or three similar structures, one of which forms a dry powder magazine for the ammunition of the South Kensington Volunteers; and the Marquis of Salisbury has built a chapel and some labourers' cottages in the same manner.

M. Coignet, in a work published within the last few months, after calling attention to the fact that the maison de garde de Vincennes had been built in concrete, (béton aggloméré), by the order of the Emperor of the French, and that several other buildings had been successfully constructed some years since by the same method, continues thus:—"Aujourd'hui le fait est certain, il ne reste plus aucun doute, le procédé est exploré dans son entier: non seulement des constructions nombreuses et importantes ont déjà été élevées, des chaussées, des trottoirs, des citernes, des toitures en forme de dôme, de cupole ou de terrasse ont été bâtis; des fosses d'aisances et un égout pour la ville de Paris, un réservoir et un arc de pont à l'Ecole des ponts et chaussées ont été construits; par ordre de S. M. l'Empereur, des essais à la mer ont été faits à Saint Jean-de-Luz; des dallages et massifs de machines pour la Capsulerie de la guerre et pour les manufactures des tabacs de Paris et de Châteauroux, des bassins en forme de vasque pour le Château de Vincennes ont été édifiés; enfin des sociétés sont déjà formées, en pleine activité, dans plusieurs départements."†

I have now adduced all the evidence I have been able to collect from the actual employment of concrete alone for the walls of buildings and retaining walls, and I consider it unnecessary to refer to the numerous successful cases in which it has been employed simply as backing to an ashlar or brick front, as I hope to shew it will do without such facing. In foundations also it is known to answer well, and blocks of concrete have been used with great success at Algiers, Alderney, Dover, and elsewhere, but such employment of it is beside my present purpose. Those, however, who have seen the Dover blocks will have no difficulty in believing that its employment might be greatly extended, and that the failures recorded have arisen from the use of unsuitable lime, or from its employment in situations for which concrete is ill adapted.

* South Kensington.

† The concrete of M. Coignet is not, however, made according to the practice of this country. He uses with the lime or cement only sand and natural or artificial dry puzzuolana; these materials are first mixed in the proportion of 1 of lime to 10 of sand and puzzuolana, very perfectly and with a very small quantity of water, in two operations. The concrete is then thrown into moulds in thin layers and beaten with heavy rammers.

The writers who have until the past year most strongly advocated in published works the general employment of concrete, are Fleuret, Rondelet, Colonel Raucourt de Charleville, and Treussart. The writer who has most discredited its general employment was our own Sir Charles Pasley, whose opinions must carry great weight wherever his name is known; but I hope to shew that on this point he was mistaken.

M. Fleuret succeeded so well with concrete making that he established a manufactory of artificial stone at Pont-à-Mousson.

M. Rondelet attributes to the goodness of the mortar of the ancient Romans and the property which it had of forming, with very small stones or bricks, structures solid and easy of execution, the great number of large edifices built under the reigns of the emperors. "This simple kind of construction, he says, which allowed of the employment of thousands of workmen at once, and which lent itself to the execution of all kinds of forms, rendered that possible which would have proved an insurmountable difficulty by any other means. Circular forms and arches require, in cut stone, and even in wood, special knowledge, great labour, materials carefully selected, or of considerable volume difficult to move and to put in place, thus occasioning much waste of time and money, whilst those of small pieces of stone become ordinary constructions requiring little care."*

In the opinion of Colonel Raucourt de Charleville, it is the want of good mortar which has most prevented the general employment of concrete in the north of Europe, and he considers that if the lime is of the proper sort there is scarcely any description of work which may not be economically and solidly executed with it. Treussart is of the same opinion; he considers that concrete may be cast in moulds for coins, copings, doors and window jambs, &c., and used even for piers of bridges over the ditches of fortresses, for the walls of sluices, for columns, obelisks, &c., constructing them on the spots they are to occupy. He thinks that it may be used to the greatest advantage for aqueduct bridges to pass canals over rivers, and to supersede arches of brick or stone; to widen a wharf wall by letting it project over the usual waterway, when that must not be encroached on, the overhanging portion of concrete forming, as it were, one immense stone with the remainder of the wall of which it makes a part. He recommends it also for forming air and watertight granaries for preserving corn in fortified places.

After observing that in some departments of the north of France they are obliged to build the mass of the revetments of their fortresses of chalk, and to protect the outside by a facing of bricks, which often gives way and requires continual and expensive repairs, he suggests that the whole of such revetments in future should be built of concrete, the exterior being coated with stucco of the same hydraulic mortar as is used for the concrete. Such revetments, he thinks, might be made thinner than brick revetments in pure lime mortar, and would not allow of the growth of vegetation which is so injurious to the joints of brickwork built in such lime.

Having proved by his experiments that prisms of good hydraulic mortar approximated to the strength of common bricks, he proposes also to build whole houses of concrete, as well as powder magazines, casemated barracks, the abutments of suspension bridges, &c.

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* Rondelet, "L'art de Bâtir."

To none of this does Sir Charles Pasley agree.

" Here I shall remark," he says, " that as far as his own experience and experiments on limes and mortars go, I consider General Treussart's opinions to be of great importance, but in the whole of his observations on béton and on artificial stone, which are almost entirely speculative, he seems to have been led away by the same sort of enthusiasm which prevailed in this country a few years ago, and which caused concrete and artificial stone to be valued so far above their real merit that many persons seemed to think that they would supersede stone altogether; but the failures of this substance in the docks and wharfs of Her Majesty's Dockyards at Woolwich and Chatham, which at first were to have been built with concrete exclusively, have brought it to its proper level by reducing it from the rival to the humble companion and assistant of stone and brickwork laid in cement; and in respect to the former in particular, my experiments have proved, rather at first to my own surprise, for I confess that I partook to a certain degree of the favourable impression alluded to, that the resistance of the best concrete after being allowed a year to set is not one-tenth part of that of Portland stone."*

In this observation of Sir Charles Pasley three points admit of question. 1st. Were General Treussart's opinions almost entirely speculative? 2nd. Might not the failures alluded to be due to causes which would not render concrete unfit for the purposes for which General Treussart recommended it? 3rd. Has not Sir Charles fallen into a serious error in assigning a position to concrete with reference to brickwork, by comparing a prism of concrete with a prism of a single piece of Portland stone?

I do not raise these questions from any desire to criticise Sir Charles Pasley's writings; few, perhaps, feel more than I do the value of his investigations in limes and cements, or have studied his work more earnestly. I have selected these remarks of his simply because they express concisely the general opinion on the subject, which opinion he probably was the means of forming—because his reputation must give them great weight—and indeed, because no other writer with whom I am acquainted has placed his objections in so definite a shape. I defend General Treussart because I believe it to be of great importance for my object to shew that in this, as in all other investigations in the use of mortars, he has written on the subject only after a long and patient course of experiments.

1st. After reading M. Fleuret's instructions on making concrete, Treussart was led to make conduits and caps of arches of fat lime, for M. Fleuret gave no rule as to the *quality* of lime to be used, and these failed. He subsequently saw through the cause of his failure and Fleuret's success, and he concludes the first Section of his work thus: " The goodness of the concrete depends on the quality of the hydraulic lime mortar. All the advantages possible have not yet been derived from this mode of construction, its advantages will be better appreciated when its use shall be more extended, and when the manner of perfecting hydraulic mortars shall be better understood." He had seen the artificial stones made at Alexandria by the Italians for the angles of buildings, Finot's artificial arch at Strasburg, and the arch at Schelestadt; and in repairing, in 1816, one of the dams which sustained the navigable canal of Strasburg in its passage across the ditches of the fortifications, he tells us that he found the facings alone were of freestone, and that all the interior was of concrete of great hardness, which led him to the belief that hydraulic lime must have been used for it, and ultimately to ascertaining the qualities of the Obernai lime, and of many other hydraulic limes of the neighbourhood. He had seen the concrete cellars at Metz. He must have known that at Lyons, concrete was often employed for wells, for quay walls, for bridge piers, and that, as Rondelet asserts, basins were there formed of concrete, which held water "comme un pot de terre cuite." * The correctness of this last statement, indeed, he, to some extent, himself verified. "It often happens," he says, "that there are casemates and cellars which in time of floods fill with water. This may be prevented by putting a structure of concrete upon the bottom, and if the water filters through the walls, by reinforcing them with a plaster of concrete. By these means we turned to profit at Strasburg several casemates, of which the floor was below the level of the water in the river and in the ditches in time of floods." In the two batardeaux at Strasburg, from which the facings were displaced, "the central mass of concrete," he tells us, "prevented a single drop of water from passing." Finally he refers in his work to the pillars of the churches of Véselay and Saint Amand, which, as has already been stated, were made of concrete.

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* Pasley on Limes and Cements. Appendix CXXI.

It cannot, then, fairly be said that General Treussart's opinions were almost entirely speculative; on the contrary, he had good precedents for each of his recommendations.

2nd. How far do the failures to which Sir Charles Pasley refers upset Treussart's opinions?

It must be remembered that after Treussart's first failure in concrete of fat lime, he concluded that the goodness of concrete depended on the quality of the lime used.† "In countries where the mortars are of bad quality," he says, "I am of opinion that it would be wrong to make them" (bomb-proofs, magazines, barracks, &c.) "of concrete." He did not then make any indiscriminate recommendation of concrete under all circumstances, and with all limes. We must therefore inquire how far the limes which Treussart had at his disposal, and those of which the wharf walls in question were built, were comparable.

We learn from Pasley's work that the strongest lime mortar made by him, when moulded into a prism 2 inches square in section, which was supported at both ends and loaded at the centre, the distance between the points of support being 3 inches, broke under a weight of 211 lbs. and a like concrete prism with 209lbs. The lime used was Dorking; with Lias lime the strongest concrete block he tried bore only 119lbs. Treussart's prisms, however, of the same size bore far greater weight when similarly treated. One mortar made with lime and tarras bore 539lbs.; another, made of hydraulic lime and sand only, bore 422lbs., the common brick of Strasburg breaking with 462lbs. It is manifest, therefore, that the two argue from different conditions. Supposing, however, that their limes had been equally good, Treussart did not recommend

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* Rondelet, L'art de Bâtir, Sect. 2, Art. 6.

† Treussart on Mortars. Summary, Sect. I.

concrete for such trying situations as those of the wharf walls at Woolwich and Chatham. Where Halling lime is used for brickwork the joint invariably perishes at or near the ground line, and those who are acquainted with mortar of Aberthaw lime know that in trying circumstances the frost attacks it also. And Sir William Denison remarks, that "had sufficient care been used in the selection of the lime, of which the latter (the walls in question) were composed, and that had Aberthaw lime been used throughout, the damage would not have been near so great."* Again, where safe from frost, concrete, through possessing considerable resistance as a whole, is eminently unsuitable for situations in which by constant collisions pebble after pebble may be detached.

The failure of concrete under such circumstances, therefore, affords little argument against its employment in revetments, magazines, &c., or for other positions for which Treussart recommended it.

The extent, however, to which Sir Charles has been misled on the subject of concrete is only apparent on considering the third point on which a question is here raised.

3rd. Has Sir Charles Pasley given us any correct information as to the position which concrete holds as a mode of building when he informs us that it has a resistance to transverse strains only one-tenth of that of Portland stone?

Sir Charles, as is well known, had a high opinion of brickwork in cement; at one time he thought that "it not only does away the thrust of arches, but what is more, even dispenses with the arch-like form altogether;" and he finally concludes with reference to cement joints with brick tiles, &c.—"that over openings they require the aid of hoop iron or some other similar bond, but that in all other cases, though inferior to stone, they are much superior to any weight or strain that can possibly act upon them." He was led to this result by experimenting on prisms of brickwork in cement, stone in cement, &c. A beam of brick and cement, 18¾ inches wide, 12 inches deep, and 36 inches between the points of support, was weighted at the centre after the beam had been formed fifty days. This is long enough for Roman cement to take up the greater portion of the strength of which it is capable. The beam broke with 2,356lbs., and this was the best result he obtained.

Calculating the value of S for this beam by the formula $S = \frac{l\,W}{4bd^2}$ we find it = 7·85.

Now, Sir William Denison broke one of the concrete headers prepared by Mr. Ranger for the wharf wall at Woolwich with a hydraulic press, the beam being supported in the same way. Its dimensions were 18 inches wide, 12 inches deep, and 23 inches between the points of support. It will naturally be supposed from Sir Charles Pasley's observations, that the weight supported would be small as compared with that of the brick in cement beam. Instead of this, however, it required 10,192lbs. to break it, and this gives for S a value = 22·6, or considerably more than twice as great as Sir Charles' strongest brick beam. The concrete had been made two years, in which time the Lias probably would not have further advanced to its ultimate strength than the Roman cement in fifty days.

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* Corps Papers. Vol. 2, p. 266.

Three stones of concrete, also two years old, 18 inches wide, 15 inches deep, and 27 inches between the points of support, were subsequently to the above experiment, sent by Sir William Denison to Sir Charles Pasley, who, rejecting one result on account of a supposed flaw, assigned for S a value of 9·5 for the mean of the other two. This is still greater than that for his own brick beam.

The beams are not indeed exactly comparable since experiments clearly show that the strength of beams of such materials as stone and lime or cement do not vary as $\frac{bd^2}{l}$. The resistance, it is believed, will not be found to increase as rapidly as the square of the depth, nor to decrease in the simple ratio of the length between the points of support, but more rapidly. Since, however, when the concrete beams had the greater depth, and the brick beam the greater length, the former had the greater strength; and when the depths were equal, but the concrete beam had the shorter bearing by 13 inches in 36 inches, its resistance was nearly 3 times that of the brick beam, it may fairly be assumed that the concrete was not the weaker of the two materials. It is strange that Sir Charles did not see that his cement brickwork, as well as the concrete tried, had only one-tenth part of the strength of Portland stone. He must, however, have written hastily on this subject or he would have perceived that it was about as reasonable to estimate the position of concrete as a mode of building by such a comparison, as to suppose that the strength of a single stone in a granite rubble wall built with bad mortar, affords any criterion by which to judge of the resistance of the wall as a whole.

But the case I am advocating is not yet placed in its strongest light. An inspection of the table following will show this. The results included in it were all obtained by fracturing prisms of concrete 2 inches square in section and 3 inches between their points of support, by a weight suspended at their centres.

No.	Name of Cement.	No. of Experiments made.	Age in months.	Age in days when immersed.	Proportion of Ballast to 1 of Cement.	Fracturing weights in lbs.	Remarks.
1	Chalk lime	6	8 to 15	not immersed	4 to 5	79·5	From Table VI, Pasley on Cements.
2	Do.	3	15 to 15·5	18 to 33	4 to 5	61·3	Do.
3	Halling lime	4	8 to 15	not immersed	4 to 5	140·4	Do.
4	Do.	4	15	18 to 33	4 to 5	142·7	Do.
5	Lias lime	6	..	..	4¾ to 6	136·3	From Tables 6 and 7, Pasley on Cements.
6	Do.	20	13	17	3	134	Chatham Experiments, by Captain Schaw and others.
7	Sheppy and Harwich mixed....	1	13	not immersed	4	102	From Table 6, Pasley on Cements.
8	Pasley's artificial cement	2	15	do.	4	51·5	Do.
9	Pasley's artificial hydraulic lime	1	14	do.	4	97	Do.
10	Do. do.	1	14	18	4	83	Do.
11	Medina	3	13	17	4	335	Chatham Experiments, by Captain Schaw and others.
12	Scott's B quality	21	13	17	5	409	Do.
13	Do.	3	13	not immersed	5	740 the lowest result	Do., One block not broken with 1330lbs.
14	Portland cement	6	13	17	4	862	Do.
15	Do.	6	13	not immersed	4	914 the lowest result	Do. Four of the six blocks first tried not broken with 1330lbs., of which 330lbs. was allowed to fall from a height of a foot.
16	Inferior brick	3	..	..	..	329	From Table VIII, Pasley on cements.
17	Well-burned brick	9	..	..	..	752	Do.
18	Bath stone	3	..	..	..	666	Do.

It will be seen from the preceding table that the quick setting cements are generally unfit for making concrete, the only exception being the Medina.*

Sir Charles Pasley's experience, however, lay only with the quick setting Harwich and Sheppy cements and that of his own manufacture, which was of similar character, and it is evident from the results he obtained (Nos. 7, 8, 9, and 10) that he had no opportunity of judging of the results of which concrete is capable. The wonderful strength of that which has been prepared with cement introduced since his time has, indeed, quite changed its position as a building material. Instead of merely equalling or somewhat exceeding the strength of brickwork in mass, it may now be so made as to rival or even surpass that of the individual selected bricks of a structure (Nos. 13, 15, and 17).

Sir Charles conceived from the results he obtained, that joints of pairs of bricks united with pure cement had four times the resistance to a tearing force, of joints made with equal parts of cement and sand, and he concluded that joints of the latter description in a short time attained to five times the strength which chalk lime mortar is capable of after thirty years. But his nett cement brickwork, made into a short beam and tested by transverse strain, bore, as we have seen, no more than a beam of almost similar dimensions of Lias concrete; therefore, the Lias lime concrete had more than 20 times the strength of brickwork in chalk lime mortar after 30 years; but small prisms of Lias lime concrete after 12 months had only double the strength of those of chalk lime concrete; therefore chalk lime concrete has 10 times the strength of chalk lime brickwork after 30 years.† So far then as we may judge from Sir Charles' experiments and conclusions, when the same lime is used in each case, concrete has ten times the strength of brickwork, and since lime concrete has only one-seventh or one-eighth of that of concrete made of the best cements for this sort of employment,‡ it may fairly be concluded that whatever the proportion may be which the resistance of concrete as a mass bears to the individual components of stone masonry, it will resist a steady transverse strain incomparably better than brickwork built in the best limes of this country.§

Concrete made of good cement will evidently bear any crushing force likely to be brought upon it, since three or four storied houses have been built in concrete of grey lime mortar. M. Coignet estimates the resistance of béton made by his method at 100 kilogrammes per square centimetre;¶ and it is stated by Mr. White, in a paper read by him before the Institute of Civil Engineers, that after thirty days the crushing weight per square inch of Portland cement concrete, (one cement to ten parts shingle), was 276 lbs., or 17·77 tons on the square foot.*

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* The use of this cement for concrete has been long advocated by its manufacturers, Messrs. Francis, Brothers, of Nine Elms, who have successfully employed it in house and wall building in a small way. It was also successfully used for the construction of a retaining sea groyne in the Isle of Wight.

† See Pasley on Limes and Cements, Tables IV and VI, and Art. 194.

‡ See preceding Table.

§ When gravel, or shingle and sand, cannot be had without transport, it may frequently be advisable to employ burned clay instead. The advantage of mixing pounded bricks with concrete is well known, and lumps of burned clay or broken bricks might, with advantage, be entirely substituted for gravel in concrete made with lime, as this has a chemical action on burned clay which is wanting, or inapplicable, with gravel, and in lime concrete the burned clay would generally have a greater resistance than the cementing material.

¶ Coignet. Des bétons agglomérés, p. 168.

It may be granted that concrete not fairly set might be picked abroad, pebble by pebble, more quickly than brickwork, but this is not a danger to which it is liable in the situations for which it is recommended in this paper, and as far as resisting steady pressure, it manifestly has the required strength, if made of a proper description of cement.

When, indeed, resistance to breaching is not a consideration, even Sir Charles Pasley allows that concrete might be used in many cases with advantage in the revetment of fortresses,† and Captain Gaubert, of the French Engineers, in his notes on Merkes' "Essay on Revetments,"‡ expresses his regret and surprise that no trial has been made of revetments in pisé work proposed by the Commandant Bergère. That this sort of construction "dont l'expérience a constaté la bonté, et qui procurerait des grandes économies," would be suitable for counterscarps, gorge walls, in the different walls not exposed to breaching, and especially where it is necessary to increase the thickness of an existing wall.

The arches mentioned by Treussart, the concrete bombproof, and the extraordinary constructions by Captain Fowke, described above, clearly shew concrete to be a fitting material for the arches of casemates, magazines, &c., as respects strength, and if it can be shewn to be as suitable in other ways as brick or stone work, it would, if it is the cheaper material, of which there is no doubt, plainly be a wise economy to adopt it for these purposes also.

The great difficulties to be contended with in casemates and magazines is the getting rid of the surplus water necessarily used to secure solidity of work, and subsequently in keeping the interior dry. In concrete work with hard stones no more water is necessary than is sufficient to convert the lime and sand mixed with the gravel into a paste. The subsequent beating when thrown into its position will secure their being sufficiently wetted for adhesion, if they have not become so in the mixing; but in bricklaying every brick has to be well wetted, and all this surplus water, together with the surplus water of the mortar, has to be got rid of before a building is really fit for occupation as a magazine.

In the 3rd paper of this volume, page 84, I have estimated, from experiments on the absorptive powers of bricks, that 43,000 ozs. of water will be contained in a rod of properly built work in ordinary stocks, and that the mortar will contain 22,000 ozs., in all about 35 gallons per cubic yard of brickwork; and Lieutenant Colonel Fisher estimated from careful experiments that the quantity of water free to evaporate from a cubic yard of green 14-inch well-built brickwork varies between 36 and 48 gallons, according to the nature of the lime and brick employed.

But to bring cement, sand, and gravel into a sufficiently wet condition for use, it is not necessary to add to the mixture more than 20 gallons of water per cubic yard, the proportions being 1 cement to 6 ballast, and of this quantity between

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* Institute of Civil Engineers. Minutes of Proceedings. Vol. XI.

† Pasley on Limes and Cements.

‡ Essai sur les différentes méthodes, &c., traduit du Hollandais et annoté par H. C. Gaubert, p. 245.

7 or 8 gallons will enter into chemical combination with the cement, leaving 12 or 13 gallons, or little more than one-third of the water contained in the brickwork, to be got rid of. Concrete is generally made with far too much water, and its eventual hardness is thereby much reduced. The quantity used should be barely sufficient to make the mortar plastic, and the apparent deficiency made up by well beating the concrete when in place. A face should be given to a concrete wall, not by laying on a coat of plaster after the surface has become dry, but by introducing sufficient mortar, between the boards and the mass of the concrete thrown in in foot layers, to give the wall a fair face. This can readily be accomplished by thrusting down the blade of a shovel, on the inner side of the retaining boards, and pressing inwards to make room for the mortar to be introduced. A few up and down movements of the shovel will then give the work a sufficiently good face.

Next, will the concrete keep the water out when once it is dry? The use made of it by the Romans for retaining water; the facts cited by General Treussart concerning the concrete of the Batardeaux and casemate floors at Strasburg; and the basins at Lyons, which hold water, according to Rondelet, like a vessel of baked earthenware, appear to give a satisfactory answer to this question. The same view concerning the impermeability of concrete of hydraulic lime by water is taken by Colonel Raucourt de Charleville, and M. Coignet proposes his béton aggloméré for large gasometer walls, asserting that where brickwork fails from the porosity of the brick or faulty, ill-filled, joints, well beaten concrete will prevent the defiltration of any perceptible quantity of water.

General Treussart, indeed, was so well satisfied with the resistance of concrete to infiltration, that he recommends it not only for casemates, but as has been already stated, for Silos (*i.e.* caves to preserve grain), to which damp is fatal.

It may astonish some to hear, that in one fort for 500 men, the asphalte coverings of the buildings may amount to as much as £13,000, without satisfactorily effecting the purpose intended, and that with a layer or two of well beaten concrete, the masons of Italy, Turkey, Persia, Morocco, and other countries, manage to make their terraced roofs so watertight as to enable gardens to be made on them without producing internal dampness. On the continent, as I am informed, the use of asphalte for covering casemates, &c., is almost entirely given up.

In the construction of magazines and casemates in concrete, it would probably be best to construct the interior half of the walls and vaults of the building with a large proportion of gravel or broken stone mixed with sand, say 9 or 10 to 1 of cementing material, and to build all the external portions with no more than 2 or 3 of broken stone and sand to 1 of cement. This would secure impermeability in the outside layer; and in the inside leave air spaces, which, in sudden changes from cold to warm weather, would prevent deposits of moisture taking place on the walls.

Even as respects resistance to artillery fire, the evidence appears to be in favour of concrete.

Treussart concluded that "it would be more difficult to make breaches in revetments of concrete than in those constructed of stone;" and this is borne out by the testimony of Sir John Jones, who states from what he had witnessed in the South of Spain, that, where the cementing material is good, "the consequences are that walls built with moderate sized, or rather with small rough stones well bedded, and their interstices well filled up with mortar, become so completely one body and so incapable of being split into large pieces, that they can only be brought down from distant batteries by being literally pounded into small particles. It would not, perhaps, be too much to assume that double the means would be required to breach such a wall over those necessary to breach the ordinary brick revetments of France and Flanders."*

The committee reporting on the small concrete bombproof at Woolwich, which was made of Dorking lime, and therefore no ways comparable with the description of concrete here recommended, and which was, moreover, only set on the surface, as testified by Sir George Harding and Sir Charles Pasley, considered the resistance to fire sufficiently good to make concrete available for small magazines, casemates, and the least exposed portions of revetments. Sir George Harding, in his own report to the Inspector General of Fortifications, considered from his observation on this bombproof, that he could "recommend its adoption in the construction of arches, both as to strength and economy, and from the similarity of the material to that used in the old Moorish walls in Spain, it may be expected to harden in the same way, those walls now hardly shewing the effect of shot upon them." "In constructing bombproofs," says Captain Fowke, "it would only be necessary to have a close boarded centering for the arches, which should be made of a good thickness, and when set the centering may be safely removed. Such is the cohesive strength of this concrete, that no lintel would be required over narrow openings, such as doors and windows, the concrete standing as a flat stone over them, without any arching or alteration in its form."

"This peculiarity of the concrete—it being, as it were, monolithic—would, it is conceived, be peculiarly adapted to the purposes of escarps, as in the event of a large part of the front of the escarp being cut up, either by breaching batteries or by mines, it appears probable that this would be by no means certain to bring down the superincumbent mass of wall."†

Our present Inspector General of Fortifications, in forwarding Captain Fowke's suggestions on the use of concrete, writes—"Should objection be made that it would be more readily breached, I believe that would not be the case, because this concrete forms so connected a mass that it will bear great openings without the upper mass falling."

Lastly, Colonel Totten, of the United States Engineers, reports, after the experiments made on embrasures in 1854—"That it would be improper to deduce strict conclusions from these firings as to the respective resistances to heavy balls afforded by granite, brickwork, and cement concrete, since a few months only had been allowed for the mortar, on which the strength of the last two depends, to harden. Walls of well jointed large stones would receive but little additional strength against a force of this nature by the induration of its thin joints of mortar, while much of the strength of brickwork, and all the strength of cement concrete, would depend thereon. . . . As anticipated, therefore, their resistances were decidedly less; and of the two for the same reason, if for no other, the cement concrete proved to be weaker than the brickwork."

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* Pasley on Limes and Cements.

† Captain Fowke on a method of reducing the cost of the heavy masonry of defensive works, by the employment of concrete pisé.

There is, however, an important observation to be made here. It has already appeared from the table given that quick setting cements are either unsuitable, or far less suitable for concrete, than those recommended in this paper, and the cement used in these experiments had such energy of setting that "a cake of pure cement immersed in water before hardening" would "in a few minutes support a wire of $\frac{1}{20}$th of an inch in diameter, loaded with the weight of 1 lb."

Of the quick setting cements of this country, the most suitable for concrete attained, after twelve months, to little more than $\frac{1}{3}$ of the resistance of the concrete shewn in column No. 13 of the preceding table, not to one-third of that shewn in No. 15; and since Colonel Totten speaks of no *great* excess of resistance of the granite over the brickwork, and of the brickwork over the concrete, may it not reasonably be inferred that the concrete, if made of the best cements for the purpose, would not have been the weakest of the three descriptions of masonry; and that it will make a good substitute for brickwork set in cement for revetments liable to breaching, and *à fortiori* for brickwork set in Lias or grey chalk lime?

In the opinion of many engineers, the support of the earth is the only point of consideration, as it is said that there is little difference between the time required to breach a strong and a weak revetment. Without agreeing in this, which is opposed to the actual results obtained by Sir John Jones in Spain, it cannot be denied that iron alone promises to afford that degree of strength which is necessary to resist the impact of iron shot; that sooner or later every other material must be shattered, and that all that we can hope to effect without the use of iron plates, is to prolong the period at which a practicable breach can be effected. Since, however, every increase in the size of the guns will enormously increase the expense of an effective iron covering, it can hardly be expected that we shall do more than plate our embrasures and (excepting in sea forts) some of the most exposed portions of the works. For the great bulk of our revetments we shall still have resort to ordinary building materials and earthen ramparts, and to dispose of these in the most effective and economical manner is a problem well worth attempting. I have, therefore, ventured to suggest the following scheme, which appears to me to combine the two objects to be aimed at—a cheap support for the earth of the revetment, and a prolongation of the time during which a breach made by artillery fire will remain impracticable. Though I believe the proposed revetment might be more cheaply constructed of concrete, yet its success does not depend on the use of that material. It is equally applicable in brickwork or other masonry laid in cement or strong hydraulic lime; or, indeed, in a modified form would be applicable when the strength of the construction is to be assisted with wrought iron.

It was shewn by Lieutenant Hope, in experiments carried on at Chatham, that so far as concerns support given to the earth in rear, the most economical disposition of material not well bound together by mortar, is to employ a thin facing wall with long thin counterforts. If the cementing substance can be depended upon, the principle might be carried further, and the piers be reduced still more in thickness, and be made longer and closer together. The deeper, however, that counterforts are carried into the rampart, the longer will the earth be supported sufficiently to prevent an assault, when the wall is being destroyed by artillery fire, and if they are near together the besieger's cannon must search out and destroy a number of them before the breach is made practicable.

This result is to a certain extent secured, perhaps, by relieving arches, as usually constructed, but these, if built in lime mortar, have the great defect, that when one pier is destroyed, the others will fall by their own thrust. The piers, too, are so far apart as to allow a slant fire to be brought upon them readily. By greatly reducing, however, the span of the vaults, as shewn in the diagram, two or three piers built in good concrete, if not more, might be shot away without causing the fall of the arches which rest on them, and further support might be given (if considered necessary) by the use of hoop-iron bond. I have long thought that a revetment constructed on this plan would not be destroyed until the greater portion of the wall and arches over the whole extent of the intended opening had been destroyed, and before this can be done an immense mass of earth must be blown away, and I now submit the idea to the friendly criticism of my brother officers.

The spaces shewn empty in the vaulted chambers are left so for three reasons —To reduce the weight upon those portions of the cellular structure not carried to the lowest level; to increase the difficulty of making an easily ascended breach, by diminishing the quantity of earth necessary for its formation; and to allow of various expedients for defending the breach against an assault. The earth and *débris* caused by breaching would always be sufficient to cover the rear walls from view, and these, and the arches which might remain perfect on each side of the opening made in the revetment, might be extemporized into loopholed walls for direct and flanking fire, the earth at their feet being thrown forward into a covering mound or counterguard whenever possible.

The amount of concrete work does not much, if at all, exceed that of brick or stonework in a Vauban revetment of similar height, and when it is asserted on good authority that work can be done in cement concrete on a large scale, where materials for it are as readily obtainable as bricks and ordinary mortar, at less than one-half the price of brickwork, there can be little doubt that this question is one well worth our attention.

In the report by Captain Alexander and Colonel (the late Sir George) Harding on the concrete bombproof built in the marshes with grey chalk lime it is stated —"From the above account, and making allowance for additional time occupied on this occasion, and presuming that gravel can be as easily procured, it is considered that concrete in foundations may be formed at one-third of the cost of brickwork, and in arches and high wall at less than one-half."*

The contract price for the concrete retaining wall at Brighton was 3s. 4d. per yard; the price of brickwork in mortar of the lime used would have been about 15s. per yard.

Captain Fowke thinks that "in positions where the gravel would be excavated from the ditch in front, its price would not exceed one-fourth that of masonry, and by a proper application of steam pug mills to mix the concrete, and trucks running on railways to tip it in, the entire scarp wall of a fortress might be constructed simultaneously with the execution of the earth-works, as, from little or no skilled labour being required, any number of navvies and trucks may be

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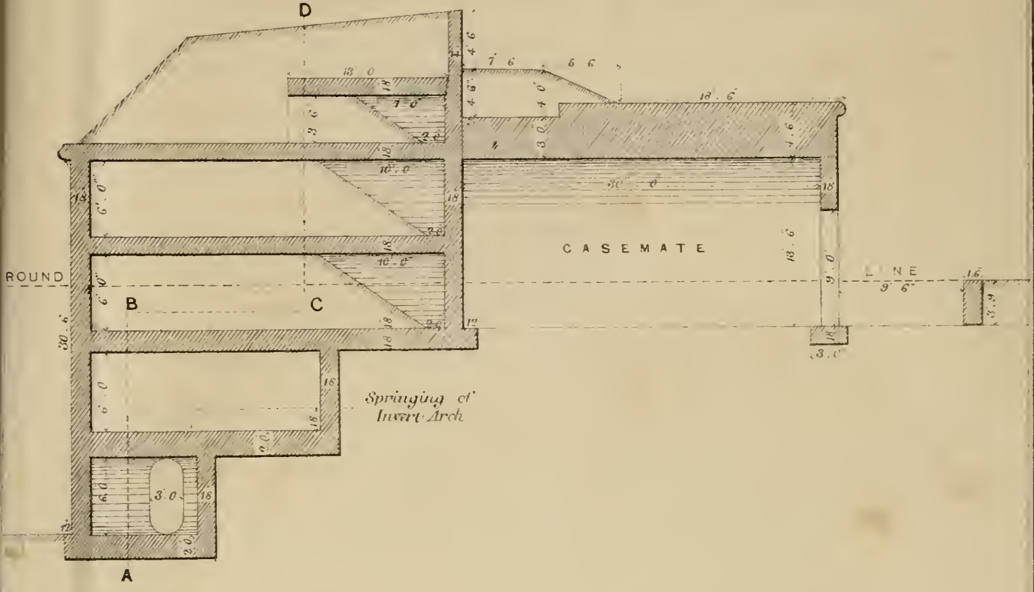
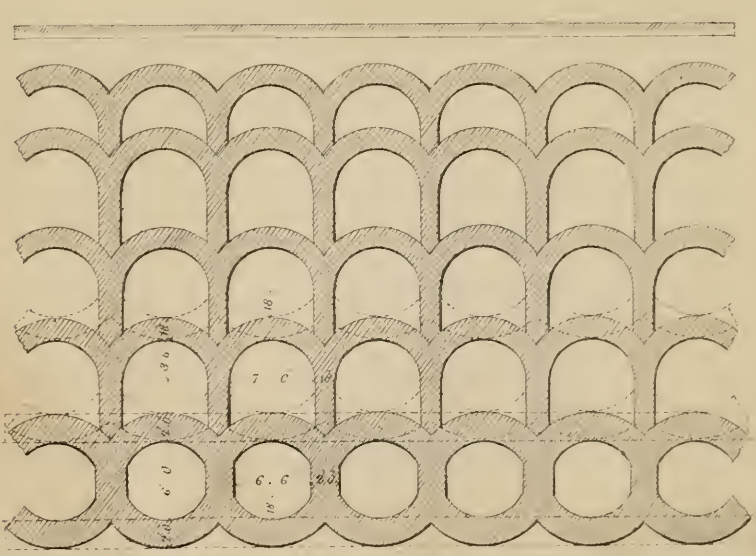
* Corps Papers, Vol. I.

SCHEME FOR A REVETMENT IN CONCRETE.

TRANSVERSE SECTION.



LONGITUDINAL SECTION ON A, B, C, D.



Scale $\frac{1}{192}$ *or 16 Feet to an Inch.*

10 5 0 10 20 30 40 50

[illegible] Lith, 257 High Holborn.

employed, as in ordinary railway work."[*] And Captain Gaubert, in his note on Merkes' work already referred to, estimates the relative prices of thick revetments in ordinary masonry and concrete, as the numbers 95 and 43; at Metz, where suitable lime can be procured on the spot, as 17 to 7; at Peronne, he states that the difference would be still greater in favour of the concrete; and adds—"Le mode de construction en pisé présenterait, outre des avantages analogues pour les revêtements en décharge, celui d'augmenter beaucoup la difficulté de faire brèche, sinon de la rendre presque impossible."[†]

I do not venture to assert as much as this, but I believe that the weight of evidence is so much in favour of the strength and cheapness of concrete, when compared with brickwork or large stone masonry, as to justify extensive trials of it in fortification works, and I think that the formation of a breach in a cellular revetment, such as I propose, would occupy a sufficient time to confute the notion that a revetment should be regarded only as a method of retaining the pressure of the earth behind it, and of keeping a work secure against surprise.

As Captain Fowke, however, remarks, "In any experiment that may be undertaken in the construction of scarps, it must be remembered that the great saving in expense will only be made apparent when the work shall be executed on a scale sufficiently large to admit of this method of construction being thoroughly systematized and reduced, as it were, to machine work."

HENRY SCOTT, Captain,
Royal Engineers.

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[*] The following are Captain Fowke's estimates (given in his paper, on a method of reducing the cost of heavy masonry of defensive works, &c.,) of the cost of erecting 100 feet in length of an escarp wall, 35 feet in height, with an average thickness of 10 feet. In one estimate the prices are for ordinary brickwork, and in the other for the same work done in concrete pisé.

"The prices are taken on the supposition that the excavation of the ditch in fronts is in gravelly soils, such as those in the neighbourhood of London, and in the surrounding counties."

"In brick earth or marly soils the earth would cost 2s. 6d. a yard extra for burning."

ESTIMATE for 100ft. run of ESCARP WALL, 35ft. × 10ft. × 100ft. = 35,000ft. = 1,296yds.

BRICKWORK.	£	s.	d.
35,000ft = 31,111ft. reduced brickwork = 114½ rods, at £10 per rod, inclusive of all material, labour, and scaffolding	1,145	0	0
Add extra in footings 2½ rods at £10	25	0	0
(Inclusive of profit.)	£1,170	0	0

CONCRETE PISE.	£	s.	d.
1,296 × 2·14 = 2,773·4 bushels cement, at 1s. 1d. per bushel	150	4	6
Labour, ·335 of a day, at 3s. 9d. per day, 1,296 yards, at 1s. 3d. per yard	81	0	0
40·35′ 0″ × 9″ × 3″ = 262′ 6″ 160·10′ 0″ × 8″ × 6″ = 533′ 4″ 25′0″ × 100′0″ × 3″ = 625′ 0″ Cubic feet timber . . . . . 1,420′ 10″ at 2d. per foot, presuming that fresh timber will be required at the end of every 1,000feet	11	16	8
12 per cent. profit	28	3	0
	£271	4	2

This is at the rate of nearly £9 saving for every foot run of walling.—H.S.

[†] Merkes. Essai sur les différentes, &c., pp. 245, 246.

PAPER XV.

NOTES ON THE CHANGES IN FIELD OPERATIONS

Likely to be caused by the Adoption of Rifled Arms,

And their effect on the Engineer Equipment.

By COLONEL BAINBRIGGE, R.E.

The carnage caused by the use of rifled ordnance in North America and China proves that a company in square, or even in line, if exposed to their fire at a distance of 2,000 yards, would soon be destroyed; and the experience gained in Canada, at the Cape, in the Crimea, and in India, teaches us that, though single individuals *moving rapidly* may pass through a great amount of musketry fire untouched, a man on horseback, *when stationary*, is almost sure to be hit by the fire of a few riflemen at a distance of 1,000 yards: hence the necessity for adopting a system very different from that formerly employed is clearly demonstrated.

The following appear to be some of the precautions which will require to be attended to, but they will of course need the modifications which experience in the field will dictate, care being taken that success is not marred by excess of caution.

1. Troops must not be massed *in large columns* when under fire, even at a range of 3,000 yards, but must be divided into separate small columns if possible, and should seldom be brought up within view of the enemy till required.

2. *When in line* under fire they should lie down whenever practicable, or be kept in such position as just to be able to fire effectually over the brow of a hill, or be placed in a ditch, or behind a hedge or wall, provided that they can fire over or through such "screens."

3. Mounted officers must be careful not to place their men where they would be too low, or too far back, to see the enemy when it is intended that they should open fire upon him, considering how much *lower* the line of vision from a kneeling man is than that from their own eyes when viewing the enemy from the same spot.

4. The men must not be allowed to fire unless they actually see the enemy, as *ineffectual firing* gives the latter confidence, and may disclose the position of those who fire, and mask the fire of others by the smoke, besides wasting ammunition (which must be economized now that the enemy must be generally under fire for longer periods than formerly).

5. It will become the duty of all company officers, after considering the form of the ground and placing their men properly, to lie down, or obtain cover in any other way, as their men do, both to set them a proper example and to prevent confusion and the withdrawal of useful men required to carry them off if wounded.

6. *Commanding Officers* of battalions must not place themselves in too prominent positions, or direct the skirmishers too much in person (except when a decisive effort is required); for if they do they will be nearly certain to be picked off, which would cause great inconvenience; besides it is their duty to *watch the movements of all around them*, and if they move about too constantly their buglers and their horses become exhausted.

7. Skirmishers and troops *extended for the purpose of attacking in force*, (which will probably be very common) must be kept under cover, if possible, until they can act with effect, then move *rapidly* to the points from whence their fire will *tell*, and be *more thoroughly* taught to seize any little hollow or bush in preference to smooth ground, and to take care that they *scatter* in moving about, and that they do not keep assembled in knots, nor even in lines, if exposed to be *enfiladed*, (in short so that the enemy may never have anything but a *small moving* object to aim at).

8. As the guns will generally be the most dangerous, the fire will be concentrated upon them first.

9. It will not be often necessary to form square, as the movements of cavalry will be much restricted by the powerful though distant fire, especially of the artillery.

10. It will be very difficult to find positions for artillery whence they can sweep all the ground within their now greatly extended range, so as to obtain all the advantages which that is supposed to afford, and at the same time such as will be tolerably safe from the fire of riflemen, therefore they must be posted with great care, so as to command all the approaches, and at the same time so as to be exposed as little as possible to the fire of the enemy's artillery or infantry; and their horses must be kept out of sight whenever it is practicable.

If these views as to the proper mode of employing troops at present should be proved by experience to be generally correct, they appear to lead to the conclusion that every effort should be made to afford, to both artillery and infantry, cover, no matter how small, as rapidly as possible wherever it does not exist, and consequently to provide the means of having an engineer equipment always with the advance, sufficient to give to every four men of the Line a pickaxe and shovel, whenever it may be desirable to set them to work to improve their cover, or to form trenches to connect important posts. If each of the four men took up the pickaxe in turn they would not be much fatigued, and yet in ordinary soil they could, if well directed, obtain sufficient cover in an hour to afford the same kind of advantage of position as that which enabled the Duke of Wellington to stop the French army at Fuente Guinaldo, with a very inferior force, by constructing trenches which would not have proved an obstacle even to cavalry.

It seems desirable, therefore, to organize detachments of the Engineer train, consisting of horses or mules provided with packsaddles for conveying tools, packed so as to be quickly distributed when required, and so as to enable them to proceed at a trot.

Every pair of animals might be led by a mounted man, and they could convey such tools as pickaxes, shovels, crowbars, and felling-axes to the advanced posts over the most difficult ground, or through roads filled with carriages which not even a cart could pass, and they could as easily retire to avoid capture.

They would enable a regiment to commence loopholing walls, forming abatis, levelling hedges, or excavating rifle-pits and trenches without delay, and thus not only *gain time*, which is always of much importance, but also exhibit *unexpectedly* to an enemy intrenchments, the strength of which he cannot test without incurring great loss.

Such works, if well traced, do not interfere with the movements of troops, and ought to give so much confidence to the defenders as to enable them to hold the posts, strengthened by them, long enough to give time for the troops in their rear to prepare to support them, and thus prevent the loss often sustained in sudden attacks by superior forces.

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